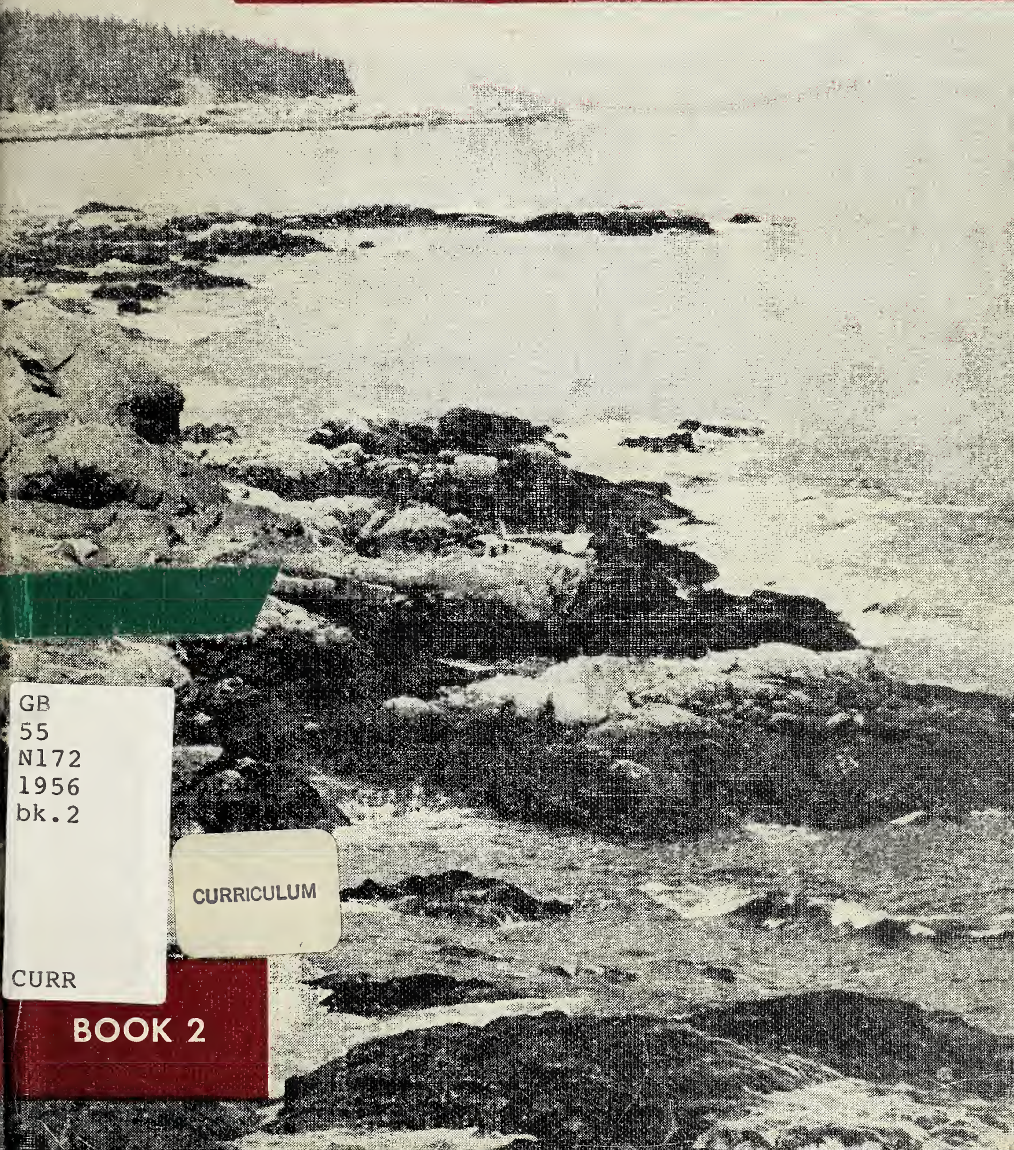
EARTH SCIENCE

CLIMATE, VEGETATION AND MAN



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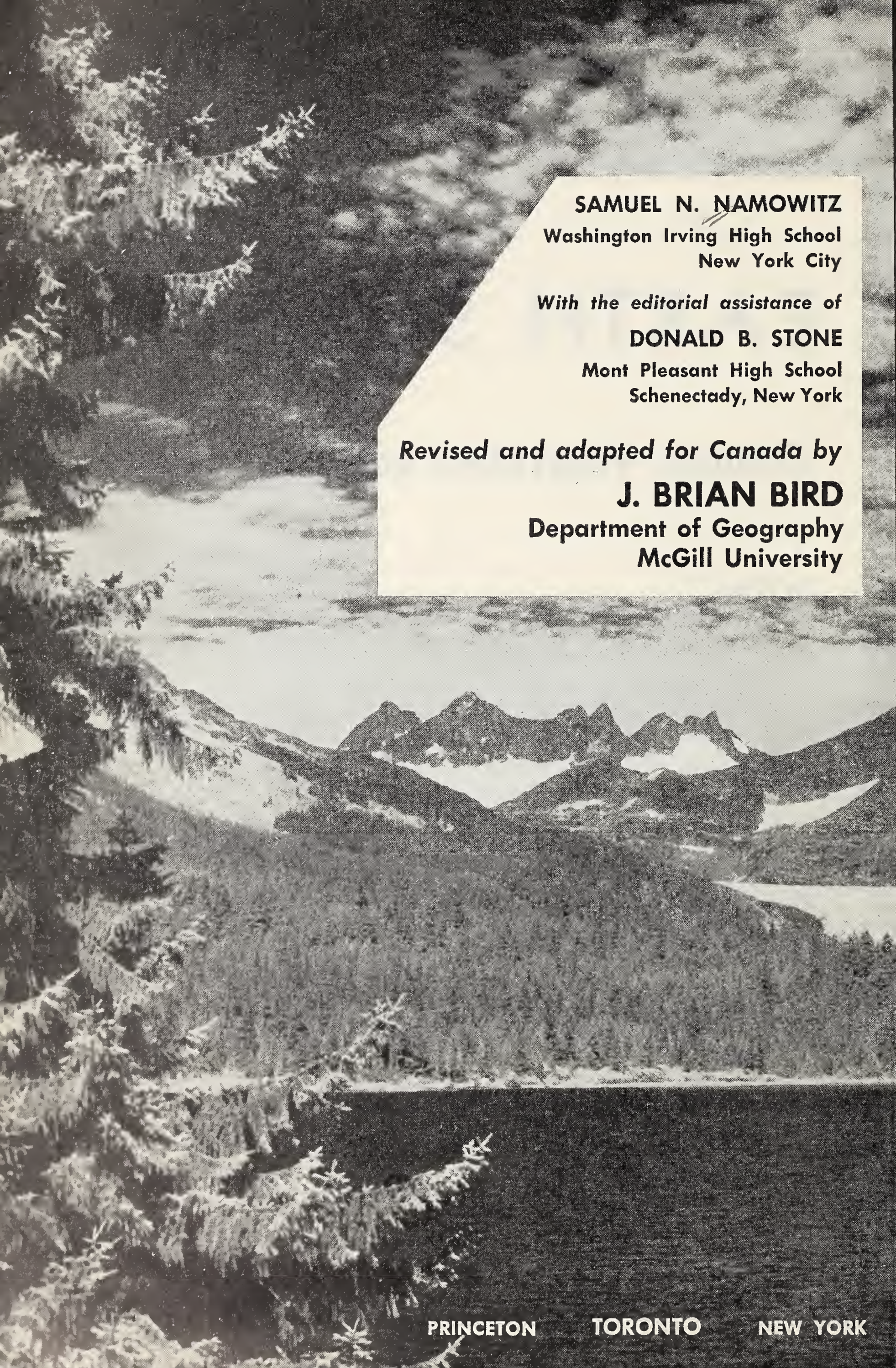

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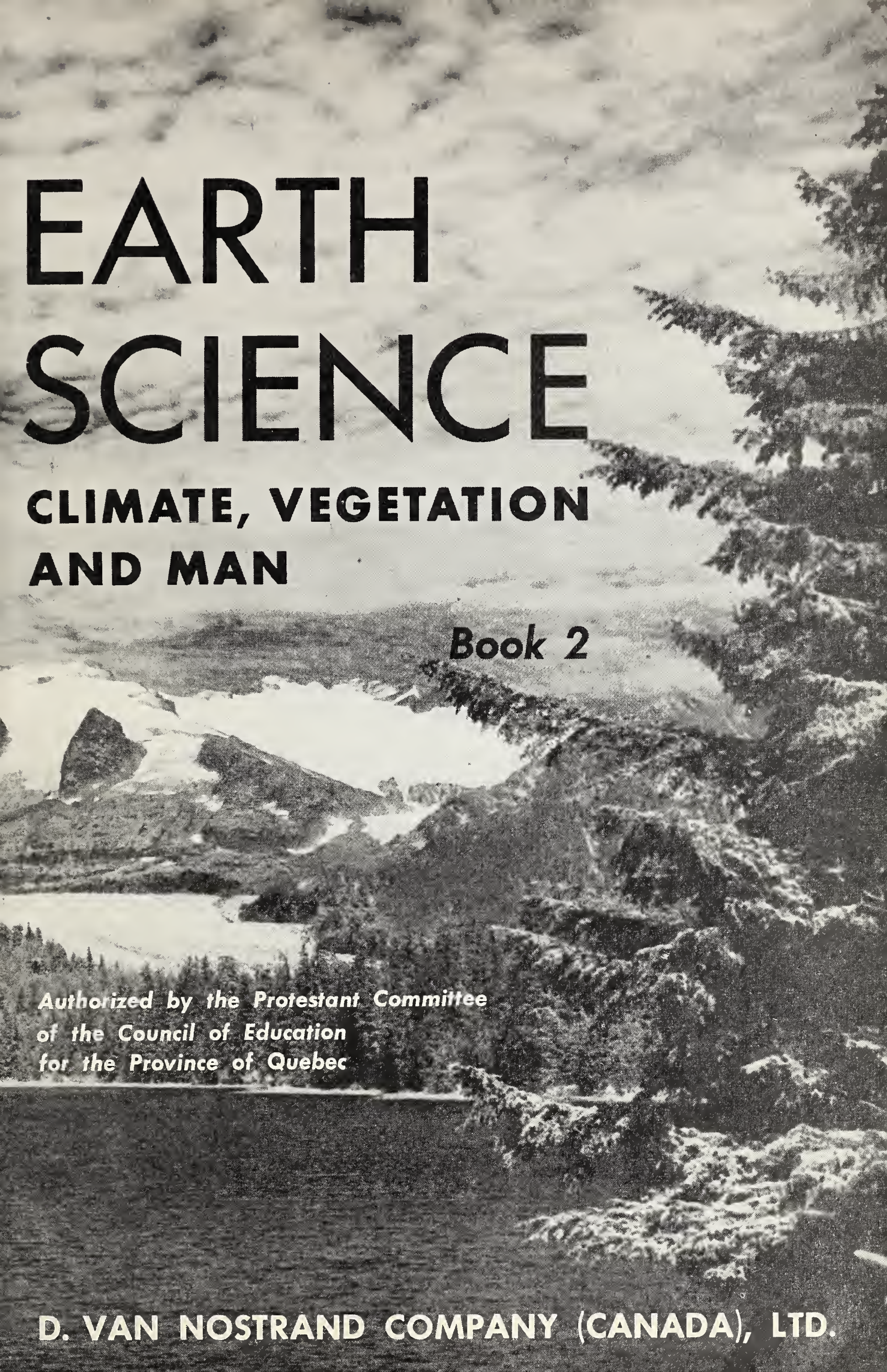

EARTH SCIENCE

CLIMATE, VEGETATION AND MAN

Book 2

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PREFACE

Geography is the study of man and his physical environment. Physical geography—or earth science—analyses the physical environment in terms of the surface of the earth, the atmosphere and the weather that develops in it, and the oceans. In Book I of *Earth Science* geomorphology (the evolution of the landscape) was studied. At all times the processes that led to the evolution of the landscape were examined as well as the landforms that resulted.

In Book II the story is completed in three broadly related units. In the first, the atmosphere and the weather processes are discussed, leading to a description of the way in which weather forecasts are made. The oceans and ocean currents are analysed in the second unit as a necessary preliminary to their influence on climate. In the third unit, the climates of the world, the vegetation and soils that have developed in response to them, and their influence on man are discussed.

The first and second units have required only slight revision from the United States edition of *Earth Science*, in keeping with differences in nomenclature and practice between Canada and the United States. In these units only Chapter 11, on the Canadian Meteorological Service, is new. The third unit has been completely rewritten and expanded to lay more emphasis on climate as a part of physical geography, and particularly the relationship between climate and man.

I would like to thank Miss Grace Fletcher, Mrs. J. C. McClatchie, Mr. Walter Coombes, Mr. Ian McKay, Mr. J. H. Taylor, Mr. George Tomkins and Mr. R. N. Wyse for their invaluable help at all stages of the revision, and I gratefully acknowledge their suggestions and advice.

J. Brian Bird

326834

PREFACE TO THE UNITED STATES EDITION

Earth science is the story of the world around us—the changing surface of the earth, the oceans and their shores, the atmosphere and its weather, and the heavenly phenomena in the universe. In brief, earth science is the story of man's physical environment.

Throughout this book, the author has aimed to develop *real* understanding of the processes and concepts with which earth science deals. The author has also sought to present basic ideas in sufficient detail to make them meaningful to high school students. A dogmatic approach has been avoided. There has been no compromise with completeness or adequacy in the treatment of topics that lie within the scope of this high school textbook.

Each chapter consists of several related *topics,* which are presented in such a way as to convey meanings rather than to require memorization. Important technical terms are italicized and pronounced when first introduced in each topic. The number of technical terms has been kept to a minimum; only those necessary for a basic understanding of concepts and processes have been used.

At the end of each chapter, there is a series of *Topic Questions.* Each topic question, consisting of one or more parts, has been written specifically to cover the principal ideas discussed in the topic of the same number within the chapter. The teacher can therefore assign questions on the basis of the topics covered in the assignment. This arrangement also aids the student in locating the answers to the question.

Instead of chapter summaries, which by their very nature must be incomplete, the author has chosen to present this information in question form under the heading, *Have You Learned These?* The student is then asked to explain in his own words the principal points discussed in the chapter. Sheer memorization is thereby discouraged. The *General Questions* require the student to apply principles learned and to tie together major points discussed in several topics or chapters. These questions can be used to advantage in classroom discussion. The variety of testing aids, *Topic Questions, Have You Learned These?,* and *General Questions* provide a complete coverage of the major points in the book.

The *Student Activities* suggest laboratory exercises, experiments, experiences, or projects related to the work of the chapter. Some of these activities may be carried out in the classroom; others outside the classroom. *Supplementary Topics* for student research and reports have been selected as interesting outgrowths of the more elementary work of each chapter. In *Suggestions for Further Reading* will be found the references needed for the investigation of the supplementary topics.

September 1953 S.N.N.

Acknowledgment of Unit Photographs

Unit I. Ice formations on Mount Washington, New Hampshire. Courtesy U. S. Department of Defense.
Unit II. Ocean Scene. Ewing Galloway.
Unit III. Palm Beach, Florida. Ewing Galloway.

CONTENTS

UNIT I THE EARTH AND ITS ATMOSPHERE

1 The Nature of the Atmosphere 2
2 Heating and Cooling of the Atmosphere 9
3 The Atmosphere's Changing Pressure 28
4 The Atmosphere's Changing Winds 39
5 Water Vapor Enters the Atmosphere 54
6 Water Vapor Condenses out of the Atmosphere 61
7 The Precipitation of Moisture 72
8 Air Masses and Their Weather 80
9 Fronts and Their Weather 87
10 Cyclones, Anticyclones, and Thunderstorms 95
11 The Canadian Meteorological Service and Its Work . . 104
12 Light and Color in the Sky 114

UNIT II THE EARTH AND ITS OCEANS

13 The Ocean and Its Currents 122

UNIT III THE EARTH AND ITS CLIMATES

14 The Factors That Control Climate 132
15 Climate, Soils, and Vegetation of the World 143
16 Tropical Climates 150
17 Mid-Latitude Climates 161
18 Polar and Mountain Climates 175

Index 184

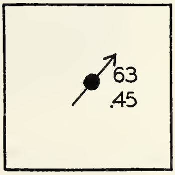
I. THE EARTH AND ITS ATMOSPHERE

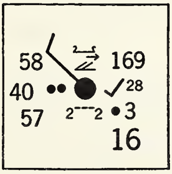
Almost three thousand years ago the ancient Greeks coined the word *meteorology*. It meant "the study of meteors." The first book on meteorology was written by Aristotle in the year 350 B.C. But the word *meteor* did not mean exactly the same thing then as it does to us today. To the Greeks, meteors were "things beyond the earth," and these things included both the heavenly bodies and the things that were seen in the atmosphere. To us, meteors are the brilliant streaks of light that we see now and then as they flash briefly against the darkness of a nighttime sky. Some people call these meteors "shooting stars," but we know that they are merely fragments of rock heated to incandescence by their swift passage through the earth's atmosphere.

Scientists of today have retained the name meteorology, but its meaning is very different from that first given to it by the ancient Greeks. Today meteorology is defined as the study of the atmosphere, with particular emphasis on weather and weather forecasting. Meteorology is a science, although not so exact a science as physics or chemistry. The reason for its lack of exactness is not hard to find. In studying the atmosphere the meteorologist is dealing with a gigantic "laboratory" whose reactions are extremely complicated, are constantly changing, and are impossible to control.

Mark Twain is said to have written that "everyone talks about the weather but no one ever does anything about it." But the modern meteorologist does do something about it, though as yet on a very modest scale. Meteorologists have taught us how to prevent frosts, how to destroy fogs, and even how to make rain. The most important work of the meteorologist, however, is his weather forecasting, the value of which is almost too great to measure. Day after day, without interruption, the forecasting meteorologist is "on the spot" before the entire country. Statistics show the weather forecasts to be correct about 85 per cent of the time, but all too often we remember only the times when the forecasts are wrong.

Meteorology has changed a good deal, not only since Aristotle's time but also in recent years. It is not so many years since nearly all weather observations were made on the ground. Nowadays observations of many weather factors which were scarcely thought of twenty years ago are being made high up in the atmosphere. The contrast between "yesterday" and "today" is strikingly shown by comparing a 1937 weather map with a 1957 weather map. In 1937 the station model—the diagram which summarizes the weather at each city—showed only four items. In 1957 it shows nearly twenty! (The full meaning of the station model is explained in the following chapters.)





Meteorology is the study of weather and weather forecasting. *Weather* is defined as the state of the atmosphere at a particular time and place. In this unit we shall try to understand why weather is so different from time to time and from place to place. We shall try to find out why places and seasons are so different in temperature, in air pressure, in winds, in humidity, in cloudiness, in rainfall, and in many other respects which we call *weather elements*. When you finish this unit, you will be able to read a weather map and make your own forecasts—or at least understand the forecasts and forgive the mistakes of the professional forecaster.

Chapter 1

THE NATURE OF THE ATMOSPHERE

1. Recipe for air. Put together a mixture of odorless, invisible gases consisting, by volume, of 78 per cent nitrogen, 21 per cent oxygen, and the remaining 1 per cent chiefly argon (0.94 per cent), a little carbon dioxide (0.03 per cent) and mere traces of neon, krypton, xenon, helium, and hydrogen. Add another trace of ozone, which has an odor. Such a mixture, practically odorless and as invisible as all of its parts, is the material we call *air*. And this air, covering the entire surface of the earth and reaching a height of at least 600 miles as it thins out into empty space, forms a great shell of mixed gases to which the name *atmosphere* is given. The atmosphere, then, is the entire gaseous shell, while the air is the material of which this shell is made.

The air that we have put together is dry and without dust. Air in this condition is referred to as "pure dry air." But in nature such air never exists, for air always contains some water vapor and some dust. Before discussing this further, let us see how we acquire our knowledge of the atmosphere.

2. Exploring the atmosphere. If the atmosphere were only four or five miles high, all our studies of it might be made by direct observation. But since it extends upward more than 600 miles, it is obvious that some of our knowledge about it must come indirectly. Here is a brief listing of both direct and indirect sources of information.

Direct observations have been made by man himself: (1) on mountains to heights of about 5½ miles; (2) in balloons to a record height of almost 14 miles; (3) in jet planes to a record height of about 15 miles. Instrument-carrying balloons have ascended to heights of about 25 miles, while rockets have already been shot to a height of

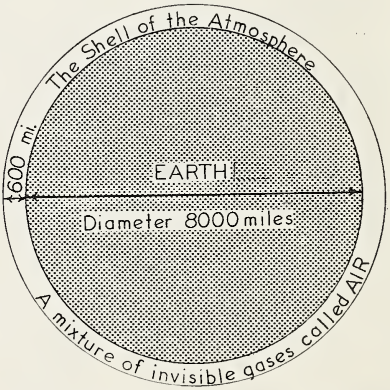

The Shell of the Atmosphere
600 mi.
EARTH
Diameter 8000 miles
A mixture of invisible gases called AIR

Fig. 1–1. The earth and its atmosphere are drawn to scale in this diagram.

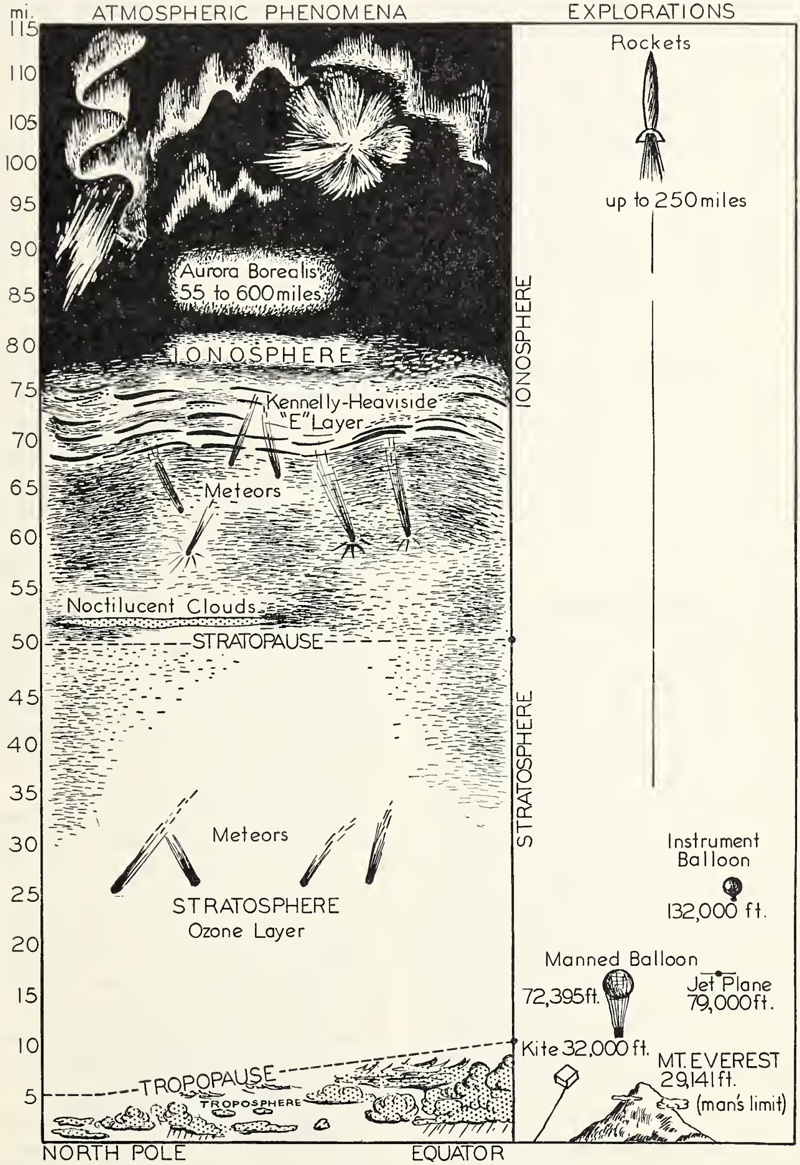


Fig. 1–2. Atmospheric phenomena and explorations.

250 miles, and may some day extend the range of instrument observations to the very top of the atmosphere.

Information about the atmosphere can be obtained *indirectly* in several ways: (1) By using the spectroscope to analyze the light of the *aurora borealis*, or northern lights, scientists may determine what gases are in the parts of the atmosphere where the lights appear. At the same time the height of that portion of the atmosphere may be measured. (2) Study of meteors, or "shooting stars," may give information about upper air temperatures. (3) Study of the reflection or absorption of sound waves, radio waves, television waves, and radar waves may give information about the existence of "layers" in the atmosphere that differ markedly from the rest of it in such characteristics as temperature and electrical properties.

3. How much atmosphere? Man has risen 22 miles into the atmosphere, has floated balloons to a height of 25 miles, and has fired rockets up to 250 miles. While most clouds occur under the 7-mile altitude, the extremely rare noctilucent (night-luminous) clouds show the presence of air at about 50 miles. The fiery rock fragments we call meteors flare up because of friction with air at even greater heights. But the 600-mile figure given as the approximate limit of the atmosphere is derived from measurements of northern lights, for these are known to be caused by electrical discharges in very thin *air*, just as the glow of a neon tube is caused by the passage of electricity through the thin gas it contains.

4. The air and its parts. Like the gases of which it is composed, air is highly compressible and highly elastic. Because air is compressible, it can be squeezed together so that it becomes denser. Because air is elastic, it expands when pressure on it is reduced. Air is very light in comparison with solids and liquids; it weighs only 1.2 ounces per cubic foot at sea level and is only 1/800 as heavy as water. But the quantity of air in the atmosphere is very great and its total weight amounts to almost 15 pounds for every square inch of the earth's surface. Air supports life on the earth, and it is the material in which weather is produced and flight is maintained.

Oxygen is the part of the air that living things require for the conversion of food into energy. *Nitrogen* forms the bulk of the air, diluting the oxygen which would poison animals and plant life in its pure form. *Carbon dioxide*, used by green plants in making starch, is also important in retaining heat near the earth's surface. *Ozone* is a highly active form of oxygen, and a remarkable absorber of ultraviolet light from the sun. It has a sharp odor like that of a freshly struck match. It is the only gas in the air that has an odor. Ozone may occasionally be smelled in the air near sparking electrical devices, since the electrical sparks turn oxygen into ozone.

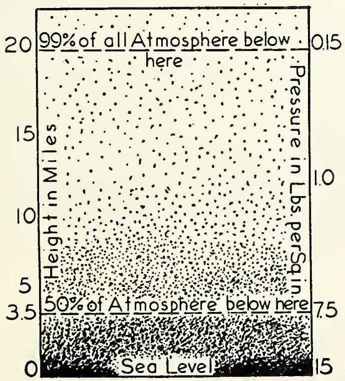
Argon, *neon*, *xenon*, and *krypton* are gases of no known importance in the atmosphere, though neon is familiar to us as the gas of neon signs, and argon is used in ordinary electric-light bulbs.

Hydrogen and *helium* are the lightest of all gases and are therefore used in lifting balloons, but the amounts of hydrogen and helium in the atmosphere are tiny, except possibly at very great heights.

Water vapor is water that has evaporated into the air and is present as a gas. Water vapor is as "dry," as invisible, and as odorless as any other gas in the air. Weather scientists regard it as the most important gas in the air, for when it condenses it forms the clouds and the rains that are necessary for all life. Compared with other gases, it is a good absorber of the sun's energy.

Dust, of course, is not a gas, but it is an important "weather" part of the air, for tiny dust particles act as "condensation nuclei" around which water vapor may condense to form cloud and rain droplets. The principal kinds of dust are: (1) dust blown up from dry soil; (2) dust from volcanic eruptions; (3) plant pollen and bacteria; (4) soot from smoking fires; (5) salt particles from sea spray. Soot and salt are especially effective in helping water vapor to condense. Microscopic dust particles are also the cause of atmospheric haze.

5. How the air compresses itself. A mountain climber finds breathing increasingly difficult the higher he climbs. Obviously it is because the air is thinner at greater heights, and each lungful of air contains fewer of the oxygen molecules he requires. In fact, at 18,000 feet, there is only half as much oxygen in a lungful of air as there is at sea level. Why should this be?



20
15
10
5
3.5
0
Height in Miles
99% of all Atmosphere below here
50% of Atmosphere below here
Sea Level
0.15
1.0
7.5
15
Pressure in Lbs. per Sq. in.

Fig. 1–3. Through its own weight, the atmosphere compresses itself to such an extent that half of all the atmosphere lies below the 3.5 mile level.

As mentioned before, air is highly compressible, and the upper air so compresses the air below it, that half the total weight of the air lies within about 3½ miles (18,000 feet) of the earth's surface, and almost 99 per cent of its total weight lies under the 20-mile level. The atmosphere can be compared to a stack of fluffy pies, one on top of the other. Though all are of the same material, the bottom one would be badly crushed, while the top one would be as fluffy as when removed from the oven.

6. Is air always the same? The air in the atmosphere is mixed so perfectly that *pure dry air* has almost exactly the same composition all over the world up to a height of at least 20 miles. The percentage of carbon dioxide is slightly higher near volcanoes and where large quantities of fuel are burned. The percentage of ozone, almost too small to mention, reaches a maximum of 1 part in 100,000 parts of air at about 20 miles elevation. Even small changes in the percentage of this "ozone layer" seem to be closely connected with weather changes near the earth's surface. Except for these two cases, there is no appreciable variation in the percentages of the components of pure dry air.

The percentage of water vapor in the air varies widely, from almost none to as high as 4 per cent by volume, depending on location, elevation, season, and time of day. Of course, when the percentage of water vapor is included in an analysis of the air, the percentages of the other components are no longer the constant figures given in Topic 1 of this chapter. For example, when air contains 2.6 per cent water vapor, it has 76.05 per cent nitrogen, 20.4 per cent oxygen, 0.9 per cent argon, and 0.05 per cent all other gases.

The dust content of the air is greatest in desert areas, near volcanoes during eruption, near factories, and in ocean areas where sea spray evaporates and leaves invisible salt particles in the air.

7. The three layers of the atmosphere. Scientists studying the atmospheric *phenomena* (things visible or observable) shown in Figure 1–2 have decided that the atmosphere consists of three distinct layers, very different from each other. These layers have been named *troposphere* (*trop* uh sfihr) *stratosphere* (*strat* uh sfihr), and *ionosphere* (eye *on* uh sfihr).

The *troposphere* extends from the earth's surface to a height that varies from about 5 miles at the Poles to about 11 miles at the Equator. In middle latitudes it is about 7 miles high. It is the region of clouds and changing weather conditions, and derives its name from the Greek word *tropikos*, meaning "turn," because the air in it is continually turning over in great currents and storms. Its other outstanding characteristic is a steady drop in temperature with increasing altitude at the average rate of about 3½ degrees Fahrenheit per 1000 feet. The point at which the temperature ceases to fall is called the *tropopause*. As its name suggests, the tropopause marks the top of the atmosphere. The warmer the climate at sea level, generally, the higher the tropopause.

The *stratosphere* extends from the tropopause to a height of about 50 miles. Its name tells us that it is the region of layerlike, or horizontal, air movement. Winds are strong and steady, skies are always clear, and there is almost no dust or water vapor. Flying conditions in the lower stratosphere are almost ideal, but the occupants of an airship must be protected against the extreme cold, the low pressure, and the lack of oxygen. At the bottom of the stratosphere the temperature is very low, about —67° F in latitude 45°. This temperature continues unchanged to a height of about 20 miles.

Recent indirect measurements indicate, however, that beyond this a rapid rise in temperature occurs, so that at about 40 miles up the temperature is approximately 200° F and may be even hotter farther up. The *stratopause* marks the top of the stratosphere.

The *ionosphere* extends from the stratopause to the top of the atmosphere. The very thin air of the ionosphere contains large numbers of electrically charged air particles called *ions*. These ions are the cause of many strange electrical effects. At some levels of the ionosphere they help to make the glow we know as the *aurora*. At other levels they collect in layers which reflect ordinary radio waves back to the earth. The best-known of these layers is called the Kennelly-Heaviside Layer (see Figure 1–2). By reflecting ordinary radio waves back to the earth over and over again, these layers help the waves to pass around the earth. Short radio waves, television waves, and radar waves are not stopped by the Kennelly-Heaviside Layer and thus may escape into space.

HAVE YOU LEARNED THESE?

Meanings of: air, atmosphere, troposphere, tropopause, stratosphere, stratopause, ionosphere

Diagrams of: atmospheric layers and atmospheric phenomena

Explanations of: how ozone and carbon dioxide vary in amount; structure and characteristics of the three layers of the atmosphere; the meanings of various atmospheric phenomena; sources of dust

Relations between: water vapor and life; dust and weather

Percentages of: oxygen and nitrogen in pure dry air; water vapor in air

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is the composition by volume of pure dry air? (*b*) Why is pure dry air practically odorless and entirely invisible? (*c*) Name two other substances always present in "natural" air. (*d*) How do the words air and atmosphere differ in meaning?

2. (*a*) What are the "direct" methods by which scientists acquire information about the atmosphere? (*b*) What information can be learned from the Northern Lights? from meteors? from radio waves?

3. (*a*) What are the altitude records for manned balloons? for instrumental balloons? for clouds? (See Figure 1-2.) (*b*) How does the flare of a meteor at a height of 60 miles show that air is present above this height? (*c*) Explain why the Northern Lights show the presence of air.

4. (*a*) List the principal gases in the air, and state what purpose each one serves in the atmosphere. (*b*) Why is dust of "weather importance"? (*c*) What are the chief kinds of dust?

5. (*a*) Why does the density of the air decrease rapidly as elevation increases? (*b*) Why is physical exertion more difficult at high elevations than at low ones?

6. (*a*) Discuss the uniformity of pure dry air. (*b*) Discuss the variations in the quantity of water vapor and dust present in air. (*c*) How does the presence of water vapor in the air change the percentage of the other principal gases (see Topic 1)?

7. Give the location and outstanding features of: (*a*) the troposphere; (*b*) the stratosphere; (*c*) the ionosphere.

GENERAL QUESTIONS

1. Why is the odor of ozone unnoticeable in the troposphere except during lightning storms?

2. What information about the air can be obtained by direct observation on a high mountain?

3. Why does a mountain climber's heart beat more rapidly at 15,000 feet than at sea level?

4. Why is it impossible to say exactly where the atmosphere ends?

5. Why don't the heavier gases separate from the lighter gases in the troposphere?

6. Why is a dust particle found at the center of every raindrop?

STUDENT ACTIVITIES

1. Determining the percentages of oxygen and nitrogen in air by experiment
2. Showing the presence of water vapor in air
3. Observing and recording atmospheric phenomena

SUPPLEMENTARY TOPICS

1. The Kennelly-Heaviside or E Layer; the Appleton Layer
2. Ozone and the Weather
3. Record Stratosphere Flights
4. Explaining the Auroras
5. Properties of the Rare Gases of the Atmosphere
6. Geissler Tubes
7. Noctilucent Clouds
8. The Stratosphere
9. The Ionosphere

SUGGESTIONS FOR FURTHER READING

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Chapter 2

HEATING AND COOLING OF THE ATMOSPHERE

1. The sun heats the atmosphere. One of the principal ways in which the "state of the atmosphere" differs from place to place and from time to time is its *temperature*. Every weather forecast includes temperatures, every weather conversation mentions temperatures, and every mountain or seashore resort advertises its attractive temperatures. This chapter will discuss the processes which give the earth's atmosphere its great variations in temperature.

The first important fact, in studying the heating of the atmosphere, is that the sun's rays supply almost all of the atmosphere's heat. This fact is easily arrived at from the following familiar information: (1) Air temperatures rise in the daytime and fall at night (see Figure 2–1); (2) the air becomes much warmer on long summer days than on short winter days; (3) the polar regions are much warmer during their six-months period of sunshine than during their six-months period of darkness.

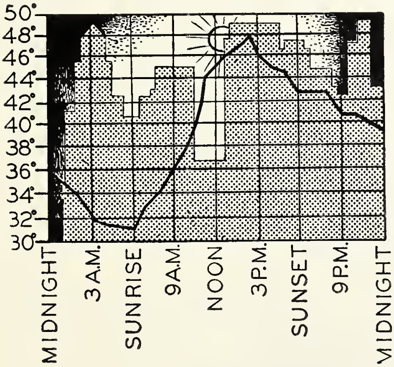


Fig. 2–1. Graph showing the rise and fall of air temperature in Montreal on a sunny day in early spring.

2. Vertical rays are hotter. The next important fact is that sunshine is not equally strong all over the earth, chiefly because the earth's surface is curved and the sun's rays strike different parts of the earth at different angles. Sunshine appears to be strongest where the rays strike the surface vertically (at right angles). The more nearly vertical the sun's rays are, the more heat they give. These facts are arrived at from such familiar knowledge as: (1) The equatorial regions, which receive close-to-vertical sunshine all year, are much warmer than the polar regions, which receive only very slanting rays (see Figure 2–2). (2) In Southern Canada, people are much more likely to be sun-

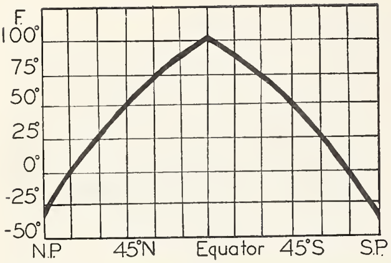


Fig. 2–2. This graph shows the range of temperature that might occur along a single meridian on the earth.

burned in June, when the sun's rays are close to vertical, than in December, when the rays are far from vertical (see Figure 2–3). (3) The sun's rays are much hotter at noon, when they are closest to vertical, than at sunrise or sunset, when they are far from vertical (see Figure 2–1).

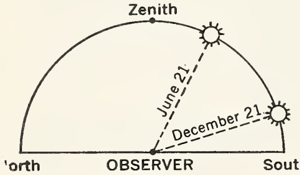


Fig. 2–3. Noon angle of the sun's rays at latitude 50° N at the sun's highest position on June 21 and its lowest position on December 21.

3. Sunshine and heat. Like a vast fire, the sun sends its energy into all of space around it, and at a distance of 93,000,000 miles a tiny fraction of this energy reaches the earth, giving it light and heat. The process by which the sun's energy passes through space is called *radiation*, and the name *insolation* is used to indicate the rays of the sun that bring this energy to the earth. (Do not confuse this word with "insulation," which means "a nonconducting material.")

The sun's rays do not always heat materials that they strike. Three things may happen to the rays, and only one of these three produces heat:

(1) When the rays strike transparent materials, such as glass, they pass right through with nearly all their energy. The glass receives little energy and little heat. *Transparent materials are good transmitters of insolation.* Empty space and thin air are good transmitters of insolation because they are transparent.

(2) When the rays strike light-colored, smooth, shiny surfaces, such as mirrors, they are reflected and bounce back with nearly all their energy. Again, the shiny surface receives little energy and little heat. *Smooth, shiny surfaces are good reflectors of insolation.* The earth's surface has no perfect reflectors, but water and snow are good reflectors of sunshine, especially when the rays come at low angles. Both the skier and the swimmer may be subjected to a "double dose" of sunshine, since they receive reflected sunshine from snow or water in addition to the sunshine that strikes them directly.

(3) When the sun's rays strike materials that neither transmit nor reflect them, they disappear into the material and are *absorbed.* Then, and only then, are the rays turned into heat, and the material is warmed. *Insolation can warm a material only when it is absorbed by that material.* There are no perfect absorbers of insolation, but, in general, solids are better absorbers than liquids, and liquids are better absorbers than gases. The darker and rougher a surface is, the less insolation it reflects and the more it absorbs. On the earth's surface, rock and soil are the best absorbers of insolation.

As a simple illustration of transmission, reflection, and absorption of sunshine, take the case of a man sitting at a window in a solarium or sun porch. The sun's rays are *transmitted* by the glass, which, having absorbed little energy, feels cold to the touch. The rays warm the man's face because his skin *absorbs* them. A mirror held at the proper angle may *reflect* additional rays onto the man's face, but the mirror itself stays cold because it absorbs no energy.

4. Why vertical rays are hotter. When we say that vertical rays are hotter than slanting rays, we actually mean that they bring more sunshine, more energy, to a given portion of the earth's surface than the slanting rays do. Figure 2–4 shows why this is so. Suppose *AB* represents a "unit" area of the earth's surface. *VV′* is a beam of vertical rays and *SS′* a beam of slanting rays of exactly the same thickness as *VV′*. (Measure them yourself to make sure.) There are two reasons why **VV′** is hotter than *SS′*:

(1) The entire vertical beam **VV′**, with all its radiant energy, strikes the area *AB*, whereas the same amount of energy in *SS′*, striking at a slant, is spread over the much larger area *AC*. In fact, the only slanting rays that strike unit area *AB* are those from *D* to *E*, not much more then one-third of the whole beam. To summarize: *vertical rays are concentrated; slanting rays are spread out.*

(2) To make matters even more favorable for the vertical rays, beam *VV′* passes through the troposphere by the shortest possible path, approximately 7 miles in middle latitudes, while the slanting path of beam *SS′* takes it through almost three times as much air, perhaps 20 miles. At sunrise and sunset, when the sun is just above the horizon, its rays may pass through more than 100 miles of troposphere. But since air, dust, and cloud particles remove much of the insolation that strikes them (by absorption and reflection), the slanting rays arrive at the earth's surface with much less energy than the vertical rays have. To summarize: *vertical rays pass through less air than do slanting rays and retain more of their energy.*

5. Temperature drops as altitude increases. Going up from the earth's surface in stationary air, temperatures are found to drop at the average rate of 3½ degrees Fahrenheit per 1000 feet. This drop in temperature is known as the *normal lapse rate*. It may seem strange that the air becomes colder rather than warmer as it gets closer to the sun. There are two reasons for this. They are explained in the next paragraph. It should be remembered, however, that a rise of a few thousand feet in the air is just "a drop in the bucket" compared with the 93,000,000-mile distance between the earth and the sun.

6. Why bottom air is warmest. (*a*) *The bottom air absorbs insolation better*

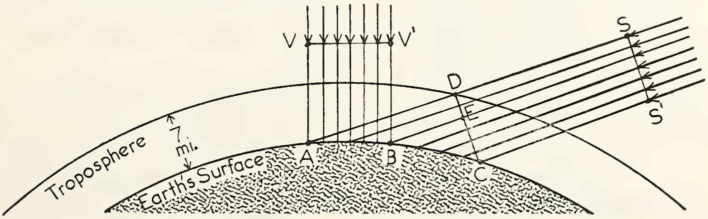


Fig. 2–4. Vertical rays bring more sunshine to a given area than slanting rays. See Topic 4.

than the upper air because it is denser, dustier, and more humid. Being denser means that there are more molecules of air in a given space which absorb sunshine. Being dustier and more humid means that the air has more particles of dust and water vapor, and these are much better absorbers than air molecules. This is extremely important, because insolation becomes heat only when it is *absorbed.*

(*b*) *The bottom air receives additional heat from the earth's surface.* The sunshine that has not been absorbed by the air reaches the earth's surface, where a good deal of it is absorbed, warming the earth. The earth, in turn, warms the bottom air in two ways: (1) Heat is passed directly into the air molecules that touch the earth, like the heat that goes from a hot stove to the kettle that sits on it. This process is called *conduction.* (2) Through *radiation,* heat is passed from the warm earth in the form of long waves which air can absorb much better than it can absorb the short waves radiated by the intensely hot sun.

The ability of air to absorb long waves from the earth after allowing the sun's short waves to pass through it is called the "greenhouse effect." It is largely due to the carbon dioxide and water vapor in the air. In a greenhouse or hothouse the glass roof transmits the sun's short waves to the soil but does not allow the long waves from the warm soil to escape to the outside.

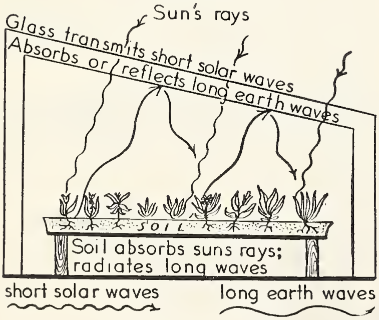


Fig. 2–5. The greenhouse effect. In the earth's atmosphere, carbon dioxide and water vapor have the same effect as the glass roof of a greenhouse.

The greenhouse effect is easily demonstrated by holding up a pane of glass, first to the sun, then in front of a hot stove or radiator. The sun's heat passes through the glass; the stove's heat does not.

7. Which is warmer—land or water? Almost all of us have had the summertime experience of racing down the burning hot sands of a beach until we could dip our feet into the refreshingly cool water just a short distance away. Why, when the same sun beats down on both land and sea, does one become so much hotter than the other? Part of the answer lies in the fact that land is a better absorber of the sun's rays than water is. But there are other reasons. Water has a higher *specific heat;* that is, it needs more heat than land does to raise its temperature a given amount. Then, too, much of the heat absorbed by water is used up in making the water evaporate rather than in warming it. A third reason is that the sun's rays penetrate deep into water, spreading out their heating effect, whereas on land all the heating takes place in a small layer of the topsoil or rock. Finally, water can distribute its heat by moving about; land cannot.

This explains why beach sands are hotter than the water in the daytime. But why are they colder than the water at night? The answer lies in the old saying "Easy come, easy go." *Good absorbers are also good radiators.* The sands radiate their heat so much faster than the water that long before sunrise they are likely to be uncomfortably chilly. The water, on the other hand, radiates its heat so slowly that it stays at almost the same temperature throughout the night. People often speak of how warm the water is at night. While it is certainly no warmer than it was during the daytime, it may feel warmer by contrast with the faster-cooling land and the air above it.

On a larger scale, the unequal heating of land and water applies to whole continents and oceans for entire seasons. In summer, continents become warmer than ocean areas in the same latitude. In winter, continents become colder than ocean areas in the same latitude.

8. Transfer of heat by convection. Thus far we have mentioned two methods of heat transfer: (1) *radiation* by means of rays or waves that pass through empty space or through transparent materials, as from the hot surface of the sun to the earth; (2) *conduction* directly through materials that are in contact, as from the warm ground to the air that rests on it, or from one end of a hot metal rod to the other. In these two methods, no visible motion of the material that is being heated is involved. But there is a third method of heat transfer that involves movement of the heated material itself. It takes place only in fluids (things that can flow; liquids and gases), and it represents a method by which heat is actually carried from one part of the material to another. This method is called *convection*. Convection is the most important method of heat transfer in the atmosphere.

To make it easy to understand convection, we shall take a simple illustration. Let the beaker of water in Figure 2–6 represent a section of the atmosphere, and let the Bunsen burner flame represent a heated portion of the earth's surface, such as a sandy beach on a hot summer day. The water directly above the flame is heated by conduction from the hot glass. The water expands the air and making it becomes less dense, or lighter in weight. Then this hotter and lighter water air "floats" to the top, moving straight up. It is more accurate to say that it is pushed up by the colder, heavier water air that surrounds it. This is actually the case, because the pull of gravity is greater on the denser cold water, which, being pulled down harder, displaces the lighter hot water. As the warmer water moves up, two things are happening that are important in spreading heat through all the water. First, the rising water is carrying heat with it to the upper waters. Second, the cold water that takes its place above the flame now has its turn at being heated. As this process continues, a steady flow of water develops, with warm water rising above the flame and cooler water sinking and moving along the bottom toward the flame. The *convection current*, as this flow is called, is completed as shown by the arrows in the diagram.

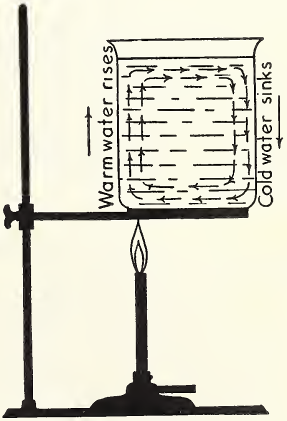


Fig. 2–6. Convection currents in water result when the water is heated from below.

If this experiment is carried out, the convection currents can easily be seen by putting sawdust into the water, or by placing a crystal of a water-soluble colored substance, such as potassium permanganate, at the bottom of the beaker, just above the flame. The flame should be a narrow one, and a wire gauze should not be used, since it will spread the heat over the bottom of the beaker.

Since liquids and gases are comparatively poor conductors of heat, it takes a long time for heat to pass through them by conduction. If convection currents were not established in the water of our beaker, it would take much longer for all the water to become heated. As before, the water at the bottom would get hot, but the water on top would remain cold for a long time. The principles of convection are applied in hot-water heaters, hot-water heating systems, hot-air heating systems, and in ventilating systems. Convection currents like those in our beaker can easily be seen in the air of a room heated by a stove or a radiator. Blow some chalk dust or smoke into the air above the heated surface and watch it soar to the ceiling. Then hold a match or candle flame near the floor close to the radiator, and watch the cool draft blow the flame toward the radiator.

To summarize, *convection is the transfer of heat by currents within the heated material.*

9. Convection in the atmosphere. Convection always takes place in fluids *if the source of heat is at the bottom* of the material being heated. This is the only necessary condition, for in this case the heated material rises after it expands and convection currents are started. On the other hand, convection does not take place if the heat comes from above, since the heated material merely stays on top as it gets hotter and lighter. At first glance, it might appear that the atmosphere is being heated from above. However, we have already seen (in Topic 6) that it is actually being heated principally at the bottom, where the earth itself behaves like the Bunsen burner or stove of our illustrations.

Heating at one side, as in our illustration, is not an essential for convection, but it does make the currents simpler and easier to see. Furthermore, such unequal heating is actually an important characteristic of heating in nature. We know that neighboring land and water areas may differ in temperature. But there are also many different kinds of land materials, each one absorbing insolation at a different rate. Dark soil and dark rocks are better absorbers than light-colored ones. Dry soil warms up faster than moist soil. Meadows warm up faster than forests. Pavements warm up faster than lawns. As a result, unequal heating of the atmosphere is always taking place, and the convection currents which are produced are responsible for the winds which we shall study in Chapter 4.

10. Heating on a sunny day. Now we can tell the whole story of the heating of the atmosphere, using the names and ideas we have already learned. Insolation streams down through clear skies, passing easily through the thin upper air. This rare upper air, with practically no dust or water vapor in it, remains very cold as it absorbs very little insolation. A small part of the insolation is reflected back into space even by the clear thin air. Only about half of the sun-energy that started through the top of the atmosphere arrives at the surface of the earth, the exact percentage depending upon the angle of the rays. The denser, dustier, more humid lower air absorbs much more insolation than does the rare upper air, so it becomes warmer. The earth's surface absorbs insolation even better. It warms up too, and then shares some of its heat with the lower air. The warm lower air rises, convection currents are created, and heat from the surface is thereby carried into the atmosphere as high as the tropopause, where convection dies out. There is a gradual drop in temperature as distance from the ground increases. At the tropopause, temperatures are far below freezing, even above the Equator, because of the great distance from the surface.

As the sun rises higher in the sky its rays become more nearly vertical and their heating power increases. The earth's surface and the air continue to warm up. As they warm up they also give off heat, but they will continue to become warmer *as long as they receive more heat than they give up.* At solar noon, when the sun reaches its highest place in the sky for the day, its rays are hottest. This is the time when you can become sunburned most rapidly. But it is not the warmest hour of the day, for the air temperature will continue to rise just as long as the air receives more heat than it gives off.

After solar noon the sun gradually goes down, but for several hours it continues to deliver more heat to the lower air than the air loses, so the air temperature continues to rise. The warmest period is therefore in the afternoon, usually between 2 P.M. and 6 P.M. The later the sunset the later the warmest hour is likely to be.

After this hour, although the sun is still shining, it is not giving the air as much heat as the air is giving off, so the air temperature drops. It will not rise again until the next morning. Figure 2–1 shows a 24-hour temperature record for Montreal on a sunny day in spring. Directly below are printed tables of hourly temperatures for typical sunny days in Winnipeg in winter and summer.

11. Cooling on a clear night. The cooling of the air is a rather simple process. Heat is lost chiefly by radiation to the upper atmosphere and beyond that into space. The lowest air may also lose heat to the ground by conduction. Cooling begins in the afternoon, as explained in Topic 10; it starts earlier in

Hourly Fahrenheit Temperatures in Winnipeg on Fair Days in Winter and Summer

A Clear Winter Day				*A Clear Summer Day*			
12 Mid.	−12°	1 P.M.	+10°	12 Mid.	64°	1 P.M.	79°
1 A.M.	−12°	2 “	+14°	1 A.M.	63°	2 “	81°
2 “	−13°	3 “	+12°	2 “	62°	3 “	83°
3 “	−14°	4 “	+8°	3 “	61°	4 “	84°
4 “	−14°	5 “	+5°	4 “	60°	5 “	83°
5 “	−15°	6 “	+3°	5 “	62°	6 “	81°
6 “	−16°	7 “	+1°	6 “	63°	7 “	80°
7 “	−16°	8 “	−1°	7 “	65°	8 “	78°
8 “	−13°	9 “	−3°	8 “	67°	9 “	77°
9 “	−9°	10 “	−6°	9 “	69°	10 “	75°
10 “	−4°	11 “	−8°	10 “	71°	11 “	73°
11 “	+1°	12 Mid.	−9°	11 “	74°	12 Mid.	71°
12 Noon	+6°			12 Noon	77°		
Sunrise 7:37 A.M. Sunset 4:22 P.M.				Sunrise 4:15 A.M. Sunset 7:33 P.M.			

All times Standard Time

winter and later in summer. After sunset no heat at all is being received and cooling continues at least until sunrise. It ends as soon as the rising sun delivers more heat than the air is giving off. Usually this is shortly after sunrise. In middle latitudes this means that the coldest hour of the day will ordinarily come between 4 A.M. and 8 A.M., varying with the season. The later the sunrise, of course, the later the coldest hour will be. See Figure 2–1 and the table on page 15 as well as your local weather records in the newspapers and other sources, for illustrations of the time of daily high and low temperatures.

12. Cloudy days and nights. Daytime clouds prevent the passage of sunshine. When the sky is completely overcast, there will be very little change in temperature, although the afternoon hours are still likely to show the highest temperatures of the day. The *temperature range*, which is the difference between the highest and the lowest temperature, will be very small. If the clouds persist at night, they act as a blanket which prevents loss of heat from the surface. The lower the cloud layer, the more effective is the blanket, since the clouds both reflect and absorb radiated heat, thus keeping it in the lower air. On cloudy nights, therefore, the air is cooled less than usual, and temperatures may remain almost constant. Nevertheless, the coldest hour of the day will probably come about sunrise, as on clear nights. The presence of dust has the same kind of effect as does cloud, but there is rarely enough dust in the air to have an appreciable effect on the day's temperatures. Study the table shown.

Hourly Fahrenheit Temperatures on a Cloudy Day in Halifax

12 Mid.	49°	1 P.M.	48°
1 A.M.	48°	2 “	49°
2 “	47°	3 “	49°
3 “	47°	4 “	48°
4 “	48°	5 “	48°
5 “	47°	6 “	48°
6 “	46°	7 “	47°
7 “	46°	8 “	47°
8 “	46°	9 “	46°
9 “	47°	10 “	46°
10 “	48°	11 “	46°
11 “	48°	12 Mid.	47°
12 Noon	49°		

Sunrise 6:18 A.M.
Sunset 5:25 P.M.

13. Temperature variations caused by sudden weather changes. Whether clear or cloudy, as long as the state of the sky remains approximately the same during a 24-hour period, the temperature record for that day will probably show the normal rise and fall associated with day and night hours. However, there are many days when normal temperature sequences are upset. One cause is a sudden change in wind direction which may bring either much colder or much warmer air, the first being a far more frequent occurrence, as with the arrival of a cold wave in winter. A second cause is the more or less sudden appearance of heavy clouds, such as thunderclouds, on what may previously have been a bright, sunny day. This is

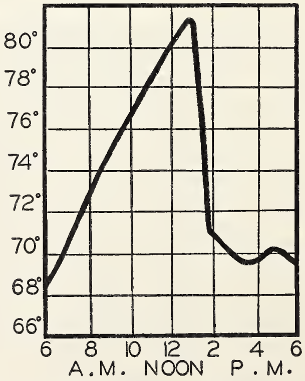


Fig. 2–7. The temperature of the air drops sharply as a result of a 1 P.M. thunderstorm at Windsor on a day in June.

a fairly common summertime weather change. A temperature graph illustrating the effect of a thunderstorm is shown in Figure 2–7.

14. Warmest and coldest months. In North Temperate climates, July is a warmer month than June, even though the sun's rays are strongest on about June 21 and daylight is longest. The explanation is the same as that for the warmest hour of the day. It is true that on June 21 the sun's rays are stronger than on any other day. With equally clear skies you may receive a worse sunburn on June 21 than on any other day of the year. It is also true that the sun shines for more hours on that day than on any other. All in all, the North Temperate Zone does receive the most insolation on June 21. But even after June 21, we continue for many days to receive more heat than we give off, and our air temperatures continue to rise each day for approximately another month. More often than not, the summer's hottest weather comes in July or even in early August.

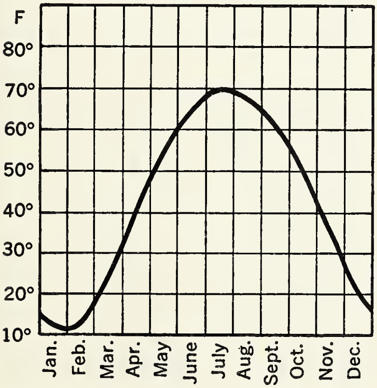


Fig. 2–8. This graph of the temperature variations from month to month at Ottawa shows that January is the coldest month and July the warmest month.

January is colder than December, because even after December 21 the air of the temperate zone continues to lose more heat than it receives from the sun. December 21 is the day of least sunshine, but the coldest days of the winter are almost always in January and February. It is not until mid-February that we begin to receive more heat daily than we lose, and it is only then that the weather begins to warm up.

15. Temperature inversions. Normally the air becomes colder as one goes up in the troposphere. Occasionally, however, it is found that the air becomes warmer as one goes upward—sometimes for as much as several thousand feet—before the normal cooling situation is resumed. Since temperatures are literally "upside down," with the warmer ones above instead of below, such a condition is called a *temperature inversion.* It occurs most strikingly on nights when the sky is clear, the air very dry, and there is no wind. These conditions permit very rapid radiation of heat from the ground and from the lower levels of the atmosphere. The cool air thus formed at the bottom of the atmosphere is very dense, so it stays at the bottom. Meanwhile the upper air loses heat less rapidly (poor absorbers are also poor radiators; see Topic 6), and by early morning it

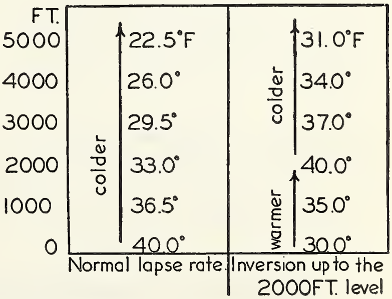


Fig. 2–9. Comparison of the normal lapse rate with a temperature inversion.

may be considerably warmer than the bottom air. Figure 2–9 shows a contrast between an inversion and a normal situation. In the chapter on the moisture of the air, it will be seen that inversions are important in causing sleet and fogs.

16. Rising air becomes colder. The normal lapse rate of 3.5 degrees Fahrenheit per 1000 feet change in elevation is true only for still air. When air *rises* in the troposphere, it comes into levels where the air pressure is less; it therefore *expands*. When a gas expands by itself, as happens here, it loses some of its heat energy, and its temperature drops. For every 1000 feet that dry air rises in the troposphere its *expansion causes cooling* of 5.5 degrees Fahrenheit. This is known as the *dry adiabatic* (add ih a *bat* ik) *lapse rate*. It is considerably more than the normal lapse rate.

Moist air cools at a different rate, and will be discussed in Chapter 6. The word *adiabatic* is used to describe a temperature change within the substance itself, caused by its own expansion or compression. No heat is taken from it or added to it by anything on the outside. Such cooling can be felt in the expanding air escaping from an automobile tire or a football bladder. In the atmosphere, the cooling of air by this method is important in cloud formation. Currents of rising air may develop as a result of convection or where winds blow over mountains. Rising air is also called *ascending* air.

17. Sinking air becomes warmer. As air *descends* in the troposphere it comes into levels of greater air pressure and is *compressed*. Energy is thus added to it, showing itself as a rise in temperature. As with rising dry air, the change is at the rate of 5.5 degrees Fahrenheit per 1000 feet. This warming by compression can be felt in the air that has just been pumped into a basketball bladder or a compressed-air tank. In nature, air warmed by compression often causes excessive evaporation and dryness.

Currents of descending air may develop through convection or where winds have crossed mountains and are on their way down. In western Canada the prevailing winds from the Pacific Ocean blow up and over the western sides of the Coast Range and the Rocky Mountains, then down their eastern sides, thus forming rising currents on the west and descending currents on the east.

18. Measuring air temperature. *Thermometers* are instruments used to measure temperature. For measuring air temperature two types are commonly used, both operating on the principle that a rise in temperature will cause expansion. *Liquid thermometers* use mercury or alcohol as the expanding material. Mercury is naturally silver-colored; alcohol is colorless but is usually dyed red or blue so that it can be seen more easily. The liquid fills the broadened bulb portion of a long tube. When exposed to higher temperatures, the alcohol or mercury expands into the almost invisibly narrow stem of the thermometer tube, which has had all air removed from it and is sealed at the top. The thermometer is made so that the glass through which the stem is viewed acts as a magnifier when held at the proper angle. On good thermometers

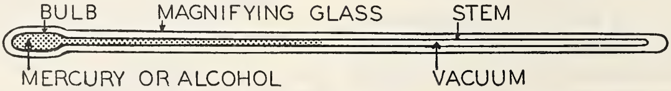
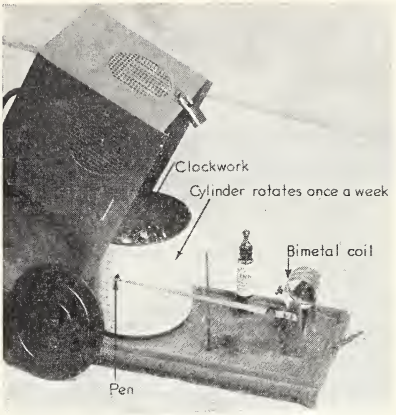


Fig. 2–10. The tube of a liquid thermometer has a broad bulb and a narrow stem.

the scale of temperatures is etched on the glass. Mercury thermometers are more accurate than alcohol thermometers because mercury expands more evenly, but mercury cannot be used in extremely low temperatures because it freezes at −39° F. Alcohol is cheaper and less accurate than mercury, but it does not freeze until it reaches −200° F.

Metal thermometers, such as oven thermometers, use a compound metal bar (a bimetal) or coil as the expanding material. When fastened at one end, such a bar will bend up or down as temperatures rise or fall; a coil will tend to wind or unwind itself. (In the Bourdon-tube type of metal thermometer, a thin curved metal tube filled with liquid is used instead of the bimetal bar.) A pointer attached to the movable end of the bar, coil, or tube will move in a circular arc over the temperature scale of the instrument.

If a pen is used instead of a pointer, and a sheet of paper marked with the temperature scale is used instead of an ordinary scale, the temperature may be recorded by the instrument as well as read directly from it. Furthermore, if this graph paper is mounted on a cylinder that is turned by clockwork at a uniform speed, the pen will write a continuous temperature record for the period of time during which the cylinder turns. Such a device is called a *thermograph*—a self-recording metal thermometer. See Figure 2–11. Usually the record is for one week, and the graph paper is divided into days and 2-hour periods. The ink used in the thermograph is a special kind, made with glycerine instead of water, to prevent freezing and evaporation. A few drops of this ink are enough for a week's record.



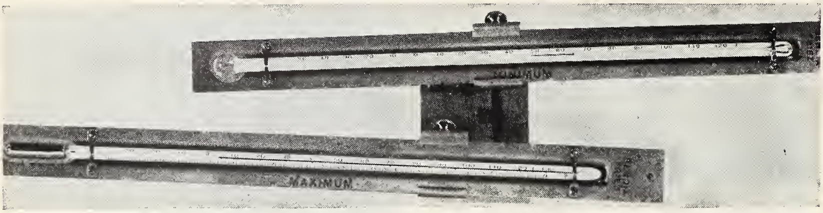
Courtesy Taylor Instrument Companies

Fig. 2–11. A thermograph of the bimetal-coil type.

While the thermograph gives a complete temperature record for the entire period observed, it is not a very accurate instrument, and other means are employed for recording the highest and lowest temperatures that occur. A *maximum thermometer* is one that records the highest temperature to which it has been exposed. A *minimum thermometer* records the lowest temperature to which it has been exposed. Like ordinary thermometers, these thermometers show the temperature of the air that surrounds them at any particular instant, but they also contain special indicators which stay at the highest (or lowest) temperature that has occurred. In the maximum thermometer, this indicator may go up but not down, until it is reset.

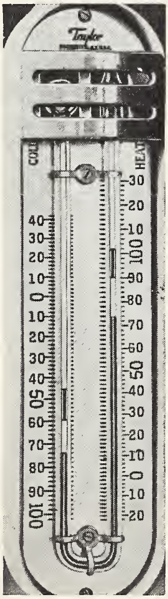
The doctor's clinical thermometer is a maximum thermometer. Since the indicator does not go down by itself, he may read it at his leisure. To reset it, he must shake it down. In the minimum thermometer the indicator may move down, but not up, unless it is reset.

There is also a combination maximum and minimum thermometer, with both thermometers in the same instrument. Figure 2–12 shows both the separate and the combination instruments.



Courtesy Friez Instrument Division

Fig. 2–12 (*a*). Maximum and minimum thermometers of the U.S. Weather Bureau type. The maximum thermometer has a constriction or narrow part in the stem just above the bulb. When air temperatures rise, the expanding mecury forces its way up past the constriction, but when temperatures fall, the mercury thread cannot fall back unless it is shaken. The minimum thermometer has a small dumb-bell shaped glass index fitting snugly in the stem. (In the photo it can be seen just above the word MINIMUM.) When the thermometer is placed with the bulb slightly lower than the top, as in the photo, this pin is dragged *down* whenever the alcohol column goes down. When temperatures rise, the alcohol forces its way past the pin without moving it. To reset the thermometer, it is merely held upside down, allowing the pin to slide to the top of the tube.



Courtesy Taylor Instrument Companies

Fig. 2–12 (*b*). Six's type of combined maximum and minimum thermometers. The steel pin or index on the left shows the minimum temperature. The pin on the right shows the maximum temperature. A magnet is used to reset the pins.

19. Temperature scales. Temperatures are measured and recorded in *degrees.* A *degree* is a definite fraction of the difference between the temperature of *melting ice* (also called the freezing point) and the temperature of *boiling water.* (Both the ice and the water must be pure and at standard sea-level air pressure.) These two temperatures are known as the *fixed points* of the thermometer. On the *centigrade scale,* which is used throughout continental Europe, the fixed points are 0° and 100° respectively, and one degree centigrade is therefore $\frac{1}{100}$th of their difference. On the less convenient *Fahrenheit scale,* which we still use in our weather observations, the fixed points are marked 32° and 212° respectively, and one degree Fahrenheit is therefore $\frac{1}{180}$th of the difference, since $212 - 32 = 180$.

Any thermometer may be marked with either or both scales, as long as the fixed points are properly indicated to begin with and the degrees properly scaled. And, of course, the thermometer need not show the entire scale from freezing point to boiling point; any portion of the scale may be used, depending on its purpose. A thermometer used for measuring outdoor air temperatures, for example, may have a range of from −40° F to 120° F, whereas a clinical thermometer may range from 94° F to 108° F. Figure 2–13 shows a comparison of Fahrenheit and centigrade scales. Note that a centigrade degree is almost twice as large as a Fahrenheit degree. To be exact, 1 degree centigrade equals 1.8 degrees Fahrenheit. To convert Fahrenheit temperatures into centigrade or vice versa, these formulas are used:

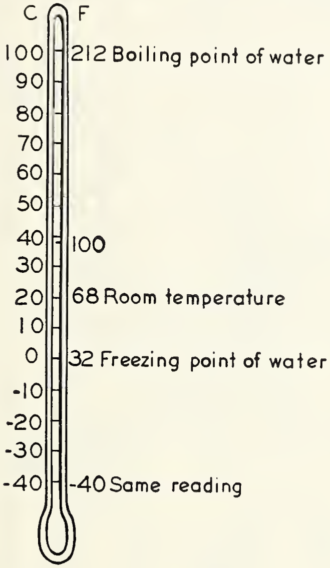


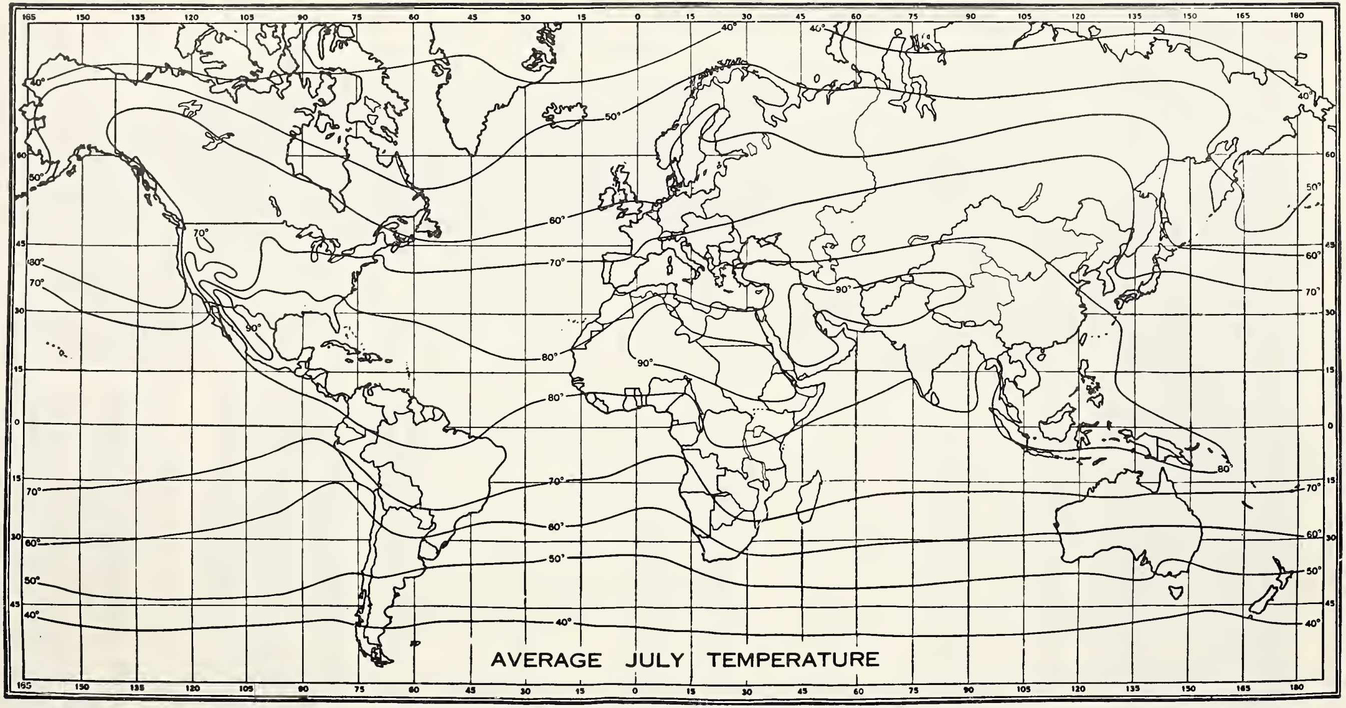
Fig. 2–13. A comparison of the centigrade and Fahrenheit temperature scales.

$$F = 9/5\,C + 32 \qquad C = 5/9\,(F - 32)$$

20. How air temperatures are shown on maps. On weather maps the air temperature for a particular city is shown as a number next to the circle marking that city's location. The number is placed to the left of the circle and a little above it, about where 10 o'clock is on a clock face. In the simplified newspaper form of the weather map, however, it is usually placed wherever convenient, but close enough to the city's circle or name to be properly identified.

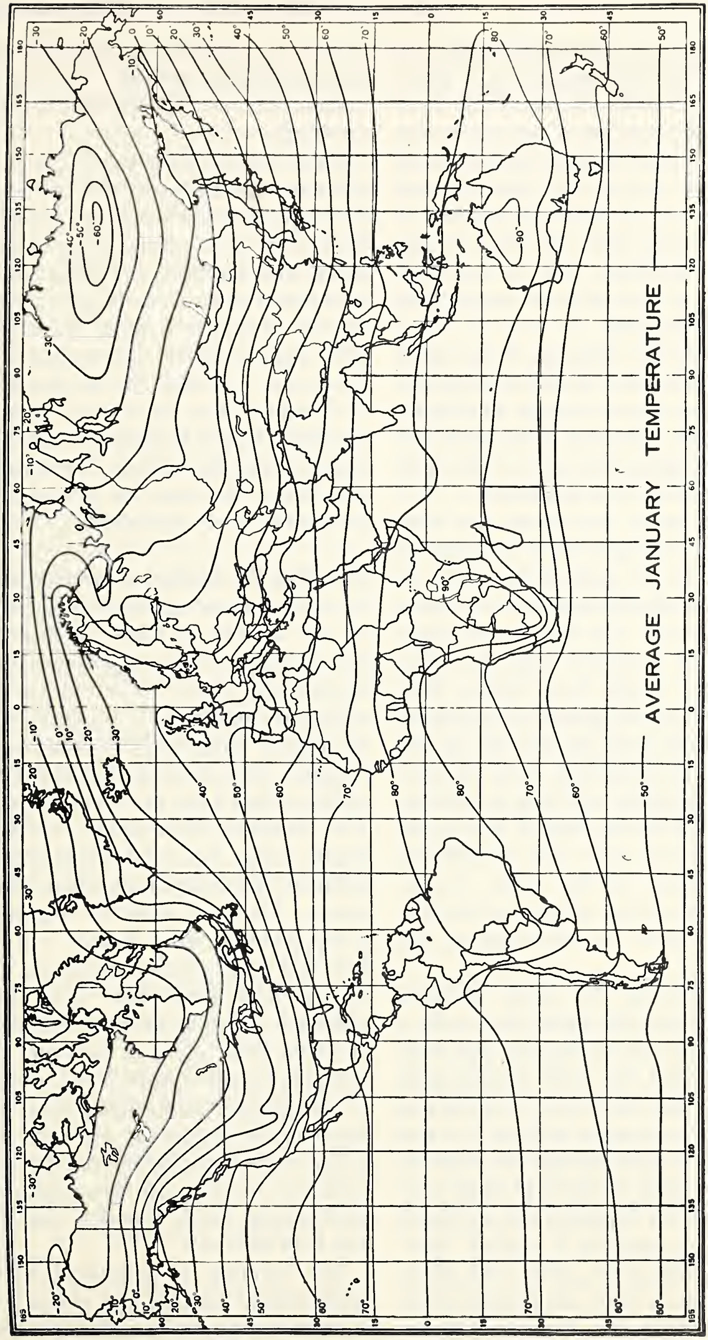
Temperatures are also shown on Canadian Meteorological Service maps and on climatic maps by using solid or broken lines called *isotherms*. The word *isotherm* means "equal heat." Isotherms are lines drawn through places which have the same temperature at a given time. They are usually drawn for intervals of 5 or 10 degrees Fahrenheit on weather maps and climatic maps, although special isotherms, such as those of 32° F (the freezing line) or 0° F may also be shown. Ordinary weather maps show temperatures at the surface, but upper-air maps also use isotherms to show temperatures at any specified height above the surface. Figures 2–14 and 2–15 show isothermal maps that indicate average temperatures for July and January for the entire world. In mountainous areas, where the temperature changes very quickly with height, an actual isotherm map becomes very complicated. The temperatures are often then, "reduced to sea level" by adding 1° F for every 300 feet of elevation; the isotherms are much simplified in consequence.

The heat equator is sometimes indicated on isothermal maps. It is a line that connects the hottest places in the world on the various meridians at any particular time. These points do not have the same temperature; the heat equator is therefore not an isotherm. Each point is simply the hottest, regardless of its temperature, for its own meridian at a given time. Thus we may have a heat equator for January, for July, for the year, or for any specified period.



Courtesy U.S. Weather Bureau

Fig. 2–14. Isothermal map of the world for July. Temperatures in degrees Fahrenheit.



Courtesy U.S. Weather Bureau

Fig. 2–15. Isothermal map of the world for January. Temperatures in degrees Fahrenheit.

21. Adding up the insolation. The average yearly temperature of a place depends to a large extent on the total amount of insolation it receives in the course of a year. This, in turn, depends upon three factors: (1) the distance from the sun, (2) the total number of daylight hours, and (3) the average angle of insolation. Let us see what the effect of each of these factors is in the course of a year.

Although the distance of the earth from the sun varies 3,000,000 miles during the year, it varies equally for all parts of the earth. Distance is therefore not a factor in giving one part of the earth more insolation than any other.

Strange as it may seem, the *total number of daylight hours in a year* is the same for all parts of the earth! It is only the distribution of these hours that is different. The Equator has about 12 hours of insolation every day. The North and South Poles receive their daylight all in one period, six months at a time, then none for the rest of the year. In the Temperate Zone the days are short in winter and long in summer. Measured in hours, there is half a year of daylight and half a year of darkness, on every part of the earth. Consequently the number of hours of daylight in a year gives no advantage to any area.

Before leaving this point, however, let us note that this factor does count a good deal on any one day and that there are days when the Poles receive more insolation than the Equator ever does in one day. For example, on June 21, when the North Pole has daylight for 24 hours, it receives about 20 per cent more insolation than the Equator does on March 21, when its sunshine is vertical. Similarly, Toronto, Ont., with 15½ hours of daylight on June 21, receives more insolation than the Equator does on March 21. Insolation at the North Pole serves mainly to melt the snow and ice surface, however, and does little to warm up the air.

Other factors being equal, the *angle of insolation* is all-important. The nearer to the Equator a place is, the nearer to the vertical is its average angle of insolation, and therefore the greater is its yearly total of insolation. At the Equator the noon sun is never more than 23½ degrees from the vertical. At Edmonton, it may be as much as 77½ degrees from the vertical, while at the North Pole it is always at least 66½ degrees from the vertical. To summarize, then: *The lower the latitude, the greater the yearly insolation.*

22. Why the isotherms are irregular. Since the amount of insolation depends on the latitude, it might be expected that isotherms, which join points of equal temperature, would follow the parallels of latitude right around the world, with the highest temperatures closest to the Equator. This would be the case if the earth's surface were absolutely uniform. The Southern Hemisphere, which is largely water, has much more regular isotherms than does the Northern Hemisphere. The chief causes of irregularity in the isotherms are as follows: (1) the fact that land absorbs insolation and radiates heat better than water does, making it hotter in summer and colder in winter than oceans in the same latitude; (2) the existence of ocean currents of contrasting temperatures along the shores of the continents, as in the case of the warm Gulf Stream and the cold Labrador Current off the coasts of northeastern North America. See Figures 2–14 and 2–15.

The "bending" of an isotherm always means that at least one part of a parallel of latitude does not have the same temperature as the rest. When an isotherm *bends toward the Pole*, the part of the parallel from which it swerves is *warmer* than the rest, since in order to maintain the same temperature, the isotherm has gone into regions that are normally colder. Conversely, when an isotherm *bends toward the Equator*, the part of the parallel from which it swerves is *colder* than the rest, since, in order to maintain the same temperature, the isotherm has gone into regions normally warmer than the parallel.

23. The shifting of the isotherms.

From June 21 to December 21 the sun's vertical rays are moving southward. From December 21 to June 21 they return northward. As they move, the heating of the earth changes, and the isotherms and heat equator may also be said to "shift with the sun." But, as explained in Topic 14, the warmest weather "lags behind the sun" by about a month, and so the heat equator and the isotherms are farthest from the Equator in July and January rather than in June and December.

Looking at the isothermal maps of Figures 2–14 and 2–15, we see, in addition to the irregularities noted in Topic 22, that: (1) the isotherms have shifted more over the Northern Hemisphere than over the Southern Hemisphere; (2) the shift is greater over the continents than over the oceans; (3) the hottest and coldest regions are always land areas; (4) the North Pole is not the coldest place in the Northern Hemisphere in winter. All these facts are easily explained on the basis of the principles studied in this chapter.

HAVE YOU LEARNED THESE?

Meanings of: insolation, radiation, conduction, convection, thermometer, thermograph, isotherm, heat equator, Fahrenheit and centigrade scales, temperature range

Diagrams of: thermometer, thermograph, vertical and slanting rays

Explanations of: normal lapse rate, dry adiabatic lapse rate, heating of the air, cooling of the air, the greenhouse effect, shifting of isotherms and heat equator, bending of isotherms, temperature inversion

Relations between: the kind of surface and its temperature; cloudiness and air temperature; angle and strength of the sun's rays

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Describe 3 sets of facts that indicate the sun to be the principal source of heat in the atmosphere.

2. Give 3 evidences that show vertical rays to be hotter than slanting rays.

3. (*a*) What is insolation? radiation? (*b*) Describe the 3 things that may happen to insolation, and state whether or not heat is produced in each case. (*c*) List the earth's best transmitters, reflectors, and absorbers.

4. With the aid of a diagram, explain why vertical rays are hotter than slanting rays. Give 2 reasons.

5. (*a*) What is meant by the normal lapse rate? (*b*) Using the normal lapse rate, work out the air temperature at the following levels, when the surface temperature is 67° F: (1) 1000 feet; (2) 5000 feet; (3) 20,000 feet. (*c*) At what level is the temperature just freezing? (*d*) Explain why the fact that air in the troposphere gets colder as it gets closer to the sun is not as strange as it may seem.

6. (*a*) Why is the bottom of the troposphere best able to absorb insolation? (*b*) In what indirect way is the lower air heated? Explain. (*c*) In what two ways does the earth's surface heat the air? (*d*) Define conduction. Give some examples. (*e*) Explain the "greenhouse effect" as it applies to air.

7. (*a*) Explain why land warms up so much faster than water under the same rays of the sun. (*b*) How does land show that it is a faster radiator of heat than water is? Explain why. (*c*) How do land and water temperatures compare: (1) by day; (2) by night; (3) in summer; (4) in winter?

8. Define convection; explain how it takes place.

9. (*a*) What condition is necessary for heating by convection? How does this occur in the atmosphere? (*b*) What condition, though not essential, is also characteristic of the convectional heating of the atmosphere? Explain why.

10. (*a*) Use a diagram to show how the air is heated on a sunny day. (*b*) Why can you get sunburned fastest at noontime? (*c*) Why does the warmest hour of the day come in the afternoon? At what time?

11. (*a*) Explain how the air cools off on a clear night. (*b*) Explain why the coldest hour of the day is approximately at sunrise. How does this vary with seasons?

12. (*a*) What is the temperature range? (*b*) Why is the daily temperature range less on a cloudy day than on a clear day?

13. Name 2 causes for a sudden rise or fall in daily temperatures.

14. (*a*) Explain why your locality is warmer in July than in June. (*b*) Explain why your locality is colder in January than in December.

15. (*a*) What is a temperature inversion? (*b*) What causes temperature inversions? When? (*c*) Compare the normal lapse rate with a temperature inversion.

16. (*a*) Explain why rising air gets colder. List the steps, or show them in a diagram. (*b*) Give a simple illustration of adiabatic cooling. (*c*) How much is the dry adiabatic lapse rate? (*d*) Name two natural occurrences of rising air currents. (*e*) If the surface temperature is 80° F, what is the temperature at a height of 4000 feet in a dry rising air current? At 10,000 feet?

17. (*a*) Explain why sinking air becomes warmer. (*b*) At what rate does it warm up? (*c*) Name 2 natural occurrences of sinking air. (*d*) How far would air have to descend in order to warm up 33° F?

18. (*a*) Explain the construction of a liquid-type thermometer. (*b*) What are the relative advantages of mercury and alcohol thermometers? (*c*) How do metal thermometers operate? (*d*) What is a thermograph? (*e*) How does a thermograph operate? (*f*) Define a maximum thermometer; a minimum thermometer.

19. (*a*) What are the fixed points of any thermometer? (*b*) What are the fixed-point temperatures on the Fahrenheit and centigrade scales?

20. (*a*) How is a city's temperature shown on the weather map? (*b*) What is an isotherm? (*c*) What is the heat equator? Explain how it differs from an isotherm.

21. (*a*) Name the 3 factors that determine the total insolation received in a year. (*b*) Which of these factors are equal for all parts of the earth. (*c*) Explain how the Poles may receive more insolation in one day than the Equator. (*d*) Why is the angle of insolation so important? (*e*) What is the relation between latitude and total yearly insolation?

22. (*a*) On what kind of planet might isotherms follow parallels of latitude exactly? (*b*) Why are isotherms so regular in the Southern Hemisphere? (*c*) Name 2 factors that cause irregularity in isotherms. (*d*) What is the meaning of poleward bending of an isotherm? of equatorward bending?

23. (*a*) Why do the world's isotherms and heat equator shift? (*b*) When are they farthest from the Equator? Why? (*c*) Where do isotherms and the heat equator show the greatest shifts? (*d*) Where are the hottest and coldest regions: (1) in July? (2) in January?

GENERAL QUESTIONS

1. While the sun is the chief source of the earth's surface heat, there are other minor sources. What are some of these?

2. Make a drawing to scale, to illustrate the statement in Topic 2 that at sunrise, the sun's rays may pass through a hundred miles of troposphere.

3. Make a diagram showing the convection currents in the air of a room heated by: (1) a central stove; (2) a radiator against one wall.

4. Why is a lake not heated by convection (see Topic 8)?

5. How do convection currents help to cool the waters of a lake in autumn?

6. Why does the stratosphere contain very little dust or water vapor?

7. Why is there very little variation in the time of the warmest and coldest hours of the day at the Equator?

8. Why is there greater variation in this (see Question 7) in Canada than in the United States?

9. What effect would a total solar eclipse have on a daily temperature record?

10. Even though you hold your face vertically to the rays of the sun in December, you will not sunburn as much in the same time as you would in June. Why?

11. Why are temperature inversions unlikely on cloudy nights, or in the daytime?

12. What liquid is used in a maximum thermometer? in a minimum thermometer? Why?

13. Why is a thermograph not very accurate?

14. Why do the Polar regions stay fairly cold even during the 6-month period of daylight?

15. Explain the 4 "irregularities" of the isothermal maps that are pointed out in Topic 22.

16. Make graphs of the temperature data given on pages 15 and 16.

STUDENT ACTIVITIES

1. Observing and keeping records of the hourly air temperatures
2. Taking care of the thermograph
3. Making graphs of hourly and daily temperatures
4. Checking the time of the warmest and coldest hours of the day
5. Checking the fixed points of a thermometer
6. Building and maintaining a thermometer shelter
7. Measuring the angle of insolation
8. Demonstrating how a pane of glass transmits the sun's short waves but not the longer waves from a stove

SUPPLEMENTARY TOPICS

1. The Relation of the Angle of Insolation to Its Percentage Strength
2. Temperature Extremes in Canada; in Australia; in the whole world
3. Conduction, Convection, and Radiation
4. The Dates of Record Temperatures
5. The Extent of Temperature Inversions
6. Maximum and Minimum Thermometers
7. Absolute Temperature Scale
8. Mountain Temperatures

See list of suggestions for further reading at the end of Chapter 1.

Chapter 3

THE ATMOSPHERE'S CHANGING PRESSURE

1. Cause of air pressure. The atmosphere is often spoken of as the "ocean of air," and man as the "deep-air animal" who lives at the bottom of the air ocean. The comparison is a good one, and particularly helpful in understanding air pressure. The pressure of the air is nothing more than the weight of the atmosphere distributed over the surface on which it rests. In Chapter 1 it was pointed out that, light as it is, air has weight; that at sea level a cubic foot of air weighs about 1.2 ounces; and that a column of air 1 square inch in cross-section and 600 miles high (from the earth's surface to the top of the atmosphere) weighs almost 15 pounds. So when we say that air pressure at sea level is equal to 14.7 pounds per square inch, we are simply saying that 14.7 pounds of air are resting on every square inch of the earth's surface at sea level.

As with water pressure, air pressure is transmitted equally in all directions, so that the pressure of 14.7 pounds per square inch is exerted by the air on all surfaces of the human body or on any other surfaces at sea level. The same pressure exists within our buildings, or in any place that is not airtight. Since inside and outside pressures are equal, neither we nor our buildings nor our "empty" bottles and cans are crushed by air pressure. But if the pressure on either side is changed, something startling does happen. Let man go too high on a mountain, where the pressure around him is greatly reduced, and he develops nosebleeds and pounding temples from the now unequalized pressure of the blood. Remove the air from within the "empty" can and the unbalanced outside air pressure crushes it. A

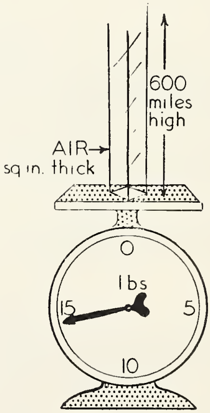


Fig. 3–1. The pressure of the air is caused by its weight.

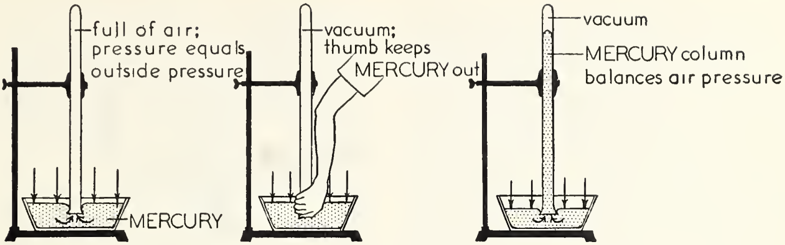

full of air; pressure equals outside pressure
MERCURY
vacuum; thumb keeps MERCURY out
vacuum
MERCURY column balances air pressure

Fig. 3–2. One way to measure the pressure of the air is to see how high a column of mercury is needed to balance it. (See Topic 2.) An instrument which measures the air pressure is called a barometer.

tornado with greatly reduced air pressure twists over a building and the unbalanced air pressure of the inside blows out the walls.

2. Measuring air pressure; mercury barometer. Measuring air pressure is like putting a 600-mile-high column of air on a scale and seeing what will balance it. The first man to perform this "trick" was the great Italian physicist Torricelli (tor reh *chel* ee). In 1643 Torricelli invented the *mercury barometer*, which balances the weight of a column of air against the weight of a column of mercury. The experiment is ingenious but very simple. Suppose we take a 36-inch narrow tube of strong glass closed at one end. The air exerts pressure against its open end, but we cannot measure this pressure as long as it is balanced by the equal pressure of the air inside the tube. However, if we pump the air out of this tube and then stand it vertical, open end down, in a bowl of liquid, the outside air pressure (no longer balanced from the inside) will force liquid up into the tube until the weight of the liquid balances the air pressure. (See Figure 3–2.)

If the liquid is a light one, like water, it will go to the very top of the tube. If it is very heavy, like mercury (13.6 times as heavy as water!), it will rise about 30 inches (at sea level) and no higher. The 30-inch column of mercury is balancing the 600-mile column of air! Above the mercury is what remains of the vacuum with which we started.

But Torricelli did not perform his experiment this way. His method was even easier. Instead of pumping the air out, he forced it out by filling the tube to the very top with mercury. Holding his thumb over the open end, he then inverted the tube into the dish of mercury. When his thumb was removed, the mercury in the tube dropped to the 30-inch level, no matter what length tube he started with, and left a vacuum above it. This vacuum in a barometer tube is still known as "Torricelli's vacuum."

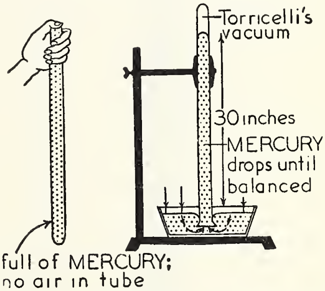


Fig. 3–3. Torricelli used a simpler method to make the mercury barometer shown in the right half of this diagram.

The cross-section of the tube may be any size at all; the larger it is, the larger is the surface against which the air pressure is transmitted through the mercury. If the tube is 1 square inch in cross-section, we find that the 30-inch column of mercury in it weighs 14.7 pounds. So our experiment shows us that *air pressure at sea level is equal to 14.7 pounds per square inch* and can balance a 30-inch column of mercury.

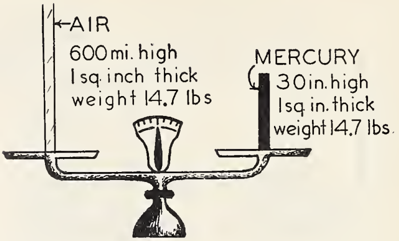


Fig. 3–5. Thirty inches of mercury and six hundred miles of atmosphere have the same weight.

3. Air pressure decreases as altitude increases. Torricelli gave the correct explanation of his barometer. He said that the pressure of the atmosphere was supporting the mercury column. But he was unable to supply proof. In 1648 another scientist carried a barometer up a mountain in France, and observed that the higher he climbed the lower the mercury column in the tube went. This strenuous experiment showed plainly that it was atmospheric pressure that was balancing the mercury. Man was leaving some of the air ocean beneath him, and so there was less air pressing down on him from above.

Courtesy M. W. Welch Scientific Co.

Fig. 3–4. The Fortin form of the mercury barometer is the type used by weather bureaus.

Today we have very accurate figures for the relation between air pressure and altitude, and we can use these figures in measuring altitude. Near sea level, a rise of 1000 feet will cause a fall of about 1 inch in the mercury column. This is only approximate, since the density of the atmosphere is not uniform. As we learned in Chapter 1, the bottom air is denser than the upper air. Half of the entire weight of the atmosphere is below the 3.5 mile level. If the mercury column is to fall 1 inch, it means that 1/30th of the total weight of the atmosphere must be left below the barometer each time. Obviously, as the air grows less and less dense, more and more air will have to be left behind to make up 1/30th of the atmosphere's weight. Figure 3–6 gives a more accurate state-

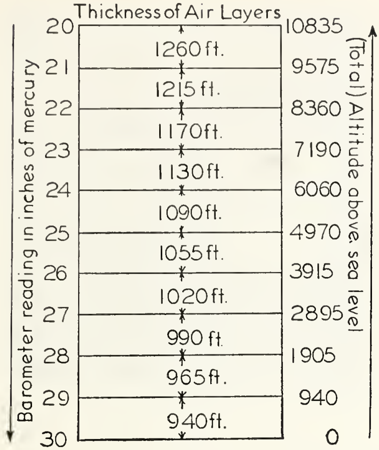


Fig. 3–6. The greater the altitude, the thinner the air. This diagram shows the approximate thickness of equal weights of the atmosphere at increasing altitudes.

ment of the relationship between air pressure and altitude. (Figure 1–3 also helps to explain this point.) But for approximate calculations up to about 10,000 feet we use the figures given above: a drop in barometer reading of 1 inch means a rise of 1000 feet; an increase in barometer reading of 1 inch means a decrease in altitude of 1000 feet. Above 10,000 feet this figure becomes too inaccurate to be useful.

4. Expressing air pressure; units. Since air pressure is measured by the mercury barometer, it is customary to express the pressure in terms of the length of the *mercury column*, which is easily measured, rather than in pounds per square inch. Normal sea-level air pressure is usually given as about 30 inches, which is a short way of saying that the air pressure is supporting a 30-inch column of mercury. Normal sea-level air pressure, expressed as a *pressure*, is nearly 15 pounds per square inch, as previously explained. Dividing 30 by 15, we see that each 2 inches of the mercury column represent, roughly, 1 pound of pressure.

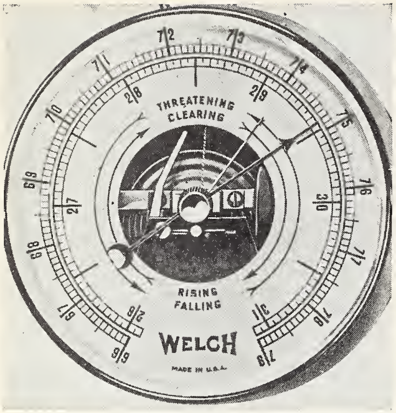
In Europe, which uses the metric system, the length of the mercury column is expressed in centimeters rather than in inches. Thirty inches are equal to about 76 centimeters. But in recent years meteorologists all over the world have adopted a metric pressure unit for expressing air pressure. This unit is called the *millibar* (abbreviated as mb.). It is equal to about one-thousandth of sea-level air pressure. The table below shows how inch units and millibars are related. The number 29.92 inches of mercury is given because it is the official *standard atmospheric pressure at sea level* averaged for the entire world; 30.5 is about as high as the barometer ordinarily reads at sea level, while 29.00 is about as low as it ordinarily reads.

Inches of Mercury	*Millibars of Pressure*
30.50	1032.9
30.00	1015.9
29.92	1013.2
29.53	1000.0
29.00	982.1
1.00*	34.0 (approx.)
0.10	3.4 "
0.09	3.0 "
0.03	1.0† "

* Use this value to convert inches of mercury into millibars.

† Use this value to convert millibars into inches of mercury.

5. The aneroid barometer; the barograph. Any instrument that measures atmospheric pressure is called a *barometer*. The mercury barometer is a very accurate instrument and is generally used by a weather bureau as its standard barometer. However, it is an awkward instrument to carry about, so another type of barometer, called the *aneroid barometer*, is often used instead. The word *aneroid* means "without liquid"; an aneroid barometer contains no liquid.

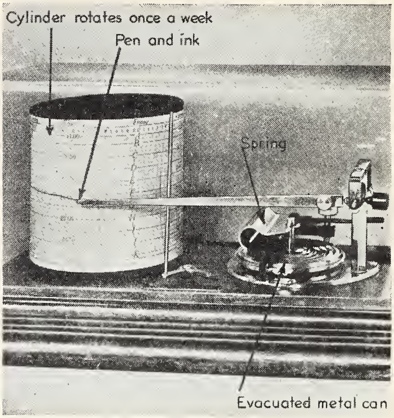


Courtesy M. W. Welch Scientific Co.

Fig. 3–7. An aneroid barometer. The evacuated metal can is visible at the center. The upper set of numbers gives pressure in centimeters; the lower set gives pressure in inches. The barometer shows a reading of 29.45 inches.

Its chief part is a small shallow metal can which has had almost all the air pumped out of it and has then been sealed airtight. This can is therefore "sensitive" to air pressure. In fact, it will collapse if it is not supported by a strong spring. To make a barometer of it, the bottom of the can is fastened down, and the top of the can is held up by the spring. When air pressure increases, the top of the can is forced down a bit. When air pressure decreases, the top of the can is pulled up a bit more by the spring. This slight movement is passed on to a pointer and enlarged. The pointer moves over a scale which is "calibrated" so that it reads the same as a mercury barometer in the same place at the same time. When calibrated to read height above sea level instead of air pressure, an aneroid barometer is called an *altimeter*.

The *barograph* is an aneroid barometer with a pen instead of a pointer, and a rotating scale sheet instead of an ordinary scale. It bears the same relation to the aneroid barometer as the thermograph bears to the metal thermometer. The barograph is a *recording barometer*.



Courtesy Taylor Instrument Companies

Fig. 3–8. A barograph, showing its principal parts.

6. Showing air pressure on maps. Air pressure is usually shown in two ways on Canadian Meteorological Service weather maps. The exact air pressure reading for a particular city, expressed *in millibars*, is written to the upper right of the station circle showing the city's location, as shown in Figure 3–9. Suppose we wish to show readings of 1013.2 mb. and 984.6 mb. On the map these will be written as 132 and 846. Notice

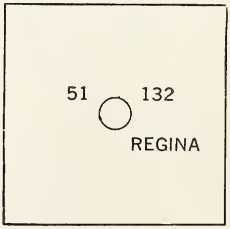


Fig. 3–9. Station model showing that temperature at Regina is 51° F and the barometer reading is 1013.2 millibars.

that the 10, the 9, and the decimal point are left out to save space. This can be done because the pressure readings always begin with a 9 or a 10, and always have one decimal place, so we need not write those parts of the readings on the map. Furthermore, practically all ordinary readings lie in the *low thousands* or the *high nine hundreds* (see table in Topic 4), so when we see a number like 13.2 we know a 10 must precede it; when we see an 84.6, we know a 9 must precede it.

The second way of showing air pressure is by *isobars* (*eye* suh barz). *Isobars* are solid lines that join points having the same air pressure at the time shown by the map. (The idea is the same as for isotherms, which join points of equal temperature. See Chapter 2.) On Canadian Meteorological Service weather maps, isobars are marked in millibars. An isobar will pass *through* a station circle only if the city's reading is exactly that of the isobar. A new isobar is drawn for each change of 3 millibars in air pressure on the map, and the millibar reading is always one that is divisible by 3. For example, consecutive isobars might be numbered 996, 999, and 1002. See the table in Topic 3 again for the relation between inches and millibars. A difference of 3 millibars is equal to a difference of .09 inches of mercury.

Newspaper weather maps usually show isobars, labeling them in both millibars and inches, but they do not show pressure readings at the station circle. Climatic maps use isobars to show average air pressures for an entire month, an entire season, or an entire year.

7. How temperature and humidity affect air pressure. We have already seen that air pressure depends on the height of the air column resting on the observer. But even when the height of the air column is the same, the air pressure may be different. For example, though both Quebec City and Halifax are approximately at sea level, they usually have different barometer readings. There are two principal reasons for this. First, *warm air is lighter than cold air*, so a column of warm air exerts less pressure than an equally large column of cold air. Secondly, *air containing water vapor is lighter than dry air*; the more water vapor, the lighter the air. This sounds contradictory, but it is easily explained. In the atmosphere, water vapor is not simply *added* to dry air. If it were, it would, of course, make the air heavier. The water vapor in

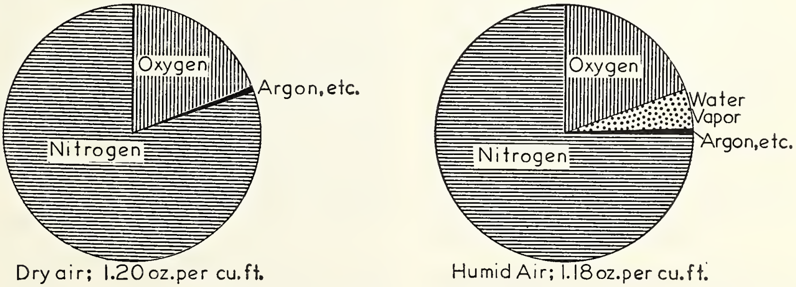


Fig. 3–10. Comparison of the composition and weight of dry air and humid air. Humid air weighs less because its water vapor weighs less than the oxygen and nitrogen it displaces.

humid air *displaces* an equal volume of dry air. For example, a cubic foot of dry air is about 99 per cent nitrogen and oxygen; but a cubic foot of humid air with 4 per cent water vapor in it contains only 95 per cent nitrogen and oxygen. *But water vapor is much lighter than either the nitrogen or oxygen whose place it took*, so the humid air is lighter than the dry air. A more exact analysis of the composition of humid air is given in Chapter 1, Topic 6.

8. World pressure belts; shifting. If the earth's surface were uniform, we might expect to find uniform distribution of air pressure along the parallels, with the lowest pressure at the Equator because of its highest temperature, and gradually increasing pressure toward the colder polar regions. But as we learned in Chapter 2, the many variations of the surface result in irregular heating of the atmosphere, so that pressure distribution, even on the basis of temperature alone, can never be as simple as just described. The land and water areas of the earth not only heat the atmosphere above them unequally, but they also contribute unequal amounts of water vapor to it, thereby introducing another cause of irregular air pressure. Consequently, when we examine a pressure map of the world we find a rather complicated distribution. For simplicity, we may at first ignore some of the irregularities and draw an "idealized diagram" of the world's pressure belts (see Figure 3–11).

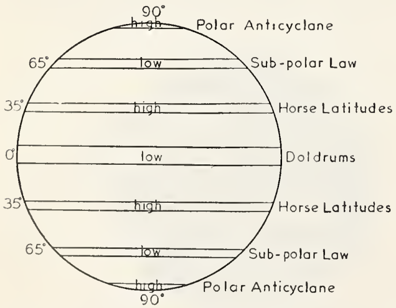


Fig. 3–11. An idealized diagram of the world's belts of high and low air pressure, showing their names and the approximate latitudes in which they occur.

This diagram represents a generalized picture of the pressure distribution that is actually observed. We can attempt to explain it as follows, but, explain it or not, it must be remembered that *this is what exists*. Briefly, we know that heating at the Equator produces an expansion and rising of the air, causing it to overflow at the top of the troposphere into higher latitudes on both sides of the Equator. Were the earth not rotating, the overflow would probably reach the Poles, causing a low-pressure belt at the warm Equator (which would lose air) and high-pressure belts at the cold Poles (which would gain air). But the earth's rotation apparently introduces complexities which result in the *sets* of pressure belts shown by our diagram. These belts are very important in determining the world's winds to be studied in the next chapter. At the Equator there is a belt of low pressure called the *doldrums* (*dol* dr'mz) belt, or belt of equatorial calms. At about 35° N and 35° S there are belts of high pressure called the *horse latitudes* or *subtropical highs*. At about 65° N and 65° S there are belts of low pressure called the *subpolar lows*. At the Poles there are belts of high pressure called the *polar highs* or *polar anticyclones* (*an* tih *sy* klohnz).

When the sun's vertical rays shift north, the doldrums belt moves north, and all the other belts shift with it. Similarly, when the sun's rays shift to the south, all the pressure belts move to the south. The distance shifted differs for different belts and parts of belts, but it is much less than the 47 degrees moved by the sun's vertical rays. Like isotherms, the pressure belts "lag" behind the sun.

9. Effect of land areas on pressure belts. If the earth's surface were uniform, the isobars would probably run around the world like the parallels of latitude, and the pressure belts would be just as shown in Figure 3–11, with their position changing as the seasons changed. In the Southern Hemisphere south of Africa, where the oceans are almost continuous and the surface therefore nearly uniform, this comes fairly close to being the case. But for the rest of the earth, the existence of both continent and ocean prevents any such regularity of the isobars and the pressure belts.

The *continents,* particularly Asia and North America, are heated in their summertime and become great centers of generally warm air and low pressure. In winter the continents are much colder than the adjoining oceans, and they become centers of generally cold air and high pressure. Consequently the belts in which the continents lie never show uniform pressures. Land pressures are almost always higher in winter and lower in summer than those of adjoining oceans. This is true even on a small scale, as in the case of such island groups as the Hawaiian Islands. It is true even for a single day at a beach, where the beach is an area of low air pressure during the sunny daytime but becomes an area of high pressure when it cools off at night.

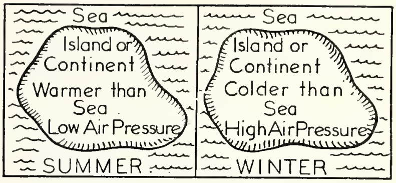
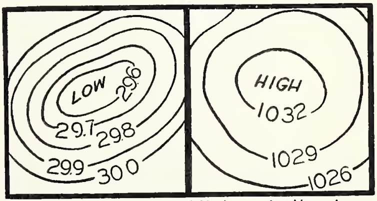

Sea
Island or Continent Warmer than Sea
Low Air Pressure
SUMMER
Sea
Island or Continent Colder than Sea
High Air Pressure
WINTER

Fig. 3–12. Land areas are usually centers of low air pressure in summer and high air pressure in winter.

Figure 3–12 shows the relative pressures of land and sea areas in summer and winter. In summer, the land will be hottest in the interior and will be generally cooler toward the shores, so pressure will be lowest in the interior and will increase gradually toward the sea. The result is an area of low air pressure which has its lowest pressure at the center. When such an area is represented on a weather map, its isobars are circles or ovals, with one surrounding the next. Such circular or oval areas of low air pressure are called *lows* or *cyclones* (*sy* klohnz). See Figure 3–13.

In winter the land is coldest in the interior and warmer nearer the sea, so pressure is highest in the interior and decreases in any direction toward the sea. On a weather map, a circular or oval area of high pressure called a *high* or *anticyclone* is seen over the land.



Low or Cyclone
Pressure in inches

High or Anticyclone
Pressure in millibars

Fig. 3–13. How areas of low air pressure (at the left) and high air pressure (at the right) are shown by isobars on a weather map.

10. Importance of barometer readings. Air pressure is always rising or falling at any one place in the temperate zone. During the course of one or two days there may be a change of as much as an inch (34 mb.) in the barometer reading. Meteorologists have learned that these pressure changes are closely connected with changes in weather. We already know that low air pressure may be due to high temperature and large water-vapor content, and that high air pressure may be due to low temperature and low water-vapor content. It is found that this agrees with observed weather phenomena, for, generally speaking, a falling barometer (decreasing air pressure) has been found to forecast warmer, more humid weather, while a rising barometer usually indicates colder and drier weather.

Modern weather forecasting goes a step further in the use of the barometer. Meteorologists have learned that lows and highs *move* along fairly definite paths across the temperate zones. If the lows and highs can be located at a particular time, it is possible to forecast where they will be in the next 24-hour period or more. Weather bureaus locate the lows and highs by having observers all over the country take barometer readings at the same moment, and then send them by telegraph or teletype to central offices. In Canada these offices are at Halifax, Montreal, Toronto, Winnipeg, Edmonton and Vancouver. From these readings, isobars are drawn on a map of North America, and the entire atmospheric pressure is shown. Forecasts made from such information are much more accurate than those made from the observation of a single barometer or barograph.

11. Reducing barometer readings to sea level. Normal air pressure for any location depends on its altitude. In Vancouver 30 inches is a normal reading. In Banff, Alberta, at 4500 feet above sea level, the normal barometer reading is about 25½ inches. But if air pressures are to be compared on a weather map and used in drawing isobars, they must all be reduced to sea-level pressure. Banff's pressure of 25½ inches is the equivalent of Vancouver's pressure of 30 inches; in other words, if Banff's atmosphere continued all the way down to sea level, its pressure at that time would be 30 inches. For this conversion to sea-level pressures, weather bureaus use very accurate tables, instead of the rough figure of 1 inch to 1000 feet.

12. Pressure gradient. Suppose that at one time the difference in pressure between Winnipeg and Montreal is 6 millibars. The weather map will show only 2 isobars between the two cities. At another time the difference may be as great as 18 millibars, and the weather map will show 6 isobars between the cities. The rate at which the pressure changes between two places (the difference in pressure for a unit distance) is called the *pressure gradient* (*gray* de unt). Since Montreal and Winnipeg are 1000 miles apart, the pressure gradient in the first case is 0.6 mb. per 100 miles. In the second case it is 1.8 mb. per 100 miles. Without doing any arithmetic, it is easy to see that when isobars are close together, the pressure gradient is large or *steep*; when isobars are far apart, the pressure gradient is small or *gentle*. The low in Figure 3–13 shows a steep pressure gradient; the high shows a gentle gradient. In this respect, pressure maps are exactly like contour maps.

HAVE YOU LEARNED THESE?

Meanings of: barometer, aneroid, barograph, millibar, isobar, low, high, pressure gradient

Diagrams of and descriptions of: mercury barometer; world pressure belts; a low; a high; the station circle and the air-pressure reading

Explanations of: shifting of the world pressure belts

Relations between: air pressure and altitude; air pressure and weather; air pressure and temperature; air pressure and humidity

Expression of: sea-level air pressure in pounds, inches, millibars

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What causes atmospheric pressure? (*b*) What small section of the atmosphere weighs about 15 pounds? (*c*) What is meant by saying that air pressure at sea level is 14.7 pounds per square inch? (*d*) Why doesn't atmospheric pressure crush an empty can? (*e*) What evidence is there that the air pressure inside a building is the same as that on the outside?

2. (*a*) Explain the idea behind Torricelli's method of measuring the atmosphere's pressure. How did he actually do it? (*b*) Make a labeled diagram of a simple mercury barometer. (*c*) Why is mercury rather than other liquids used in the liquid barometer? (*d*) How can a mercury barometer be used to prove that sea-level air pressure is 14.7 pounds per square inch?

3. (*a*) How was it proved that atmospheric pressure supports the mercury column of a barometer? (*b*) What is the average change in atmospheric pressure with altitude? Using this figure, at what altitude is the pressure 25 inches? 22 inches? What is the barometer reading at 1000 feet? (Assume sea-level pressure to be 30 inches.) (*c*) Why is the change in barometer reading with altitude not uniform? (*d*) Under what altitude do we find half the weight of the atmosphere?

4. (*a*) When we say that the air pressure is 30 inches, what do we really mean? (*b*) Express standard sea-level pressure in both inches and millibars. (*c*) How many millibars are equivalent to 1 inch of mercury? (*d*) What part of an inch of mercury is equivalent to 3 millibars?

5. (*a*) Define a barometer. What is an aneroid barometer? (*b*) With the aid of a diagram, explain the action of an aneroid barometer. (*c*) What is meant by "calibrating" the aneroid barometer? What is an altimeter? (*d*) Define a barograph; explain its action.

6. (*a*) What are the barometer readings at cities which have the following numbers next to their station circles on the weather map: 957? 113? 891? 132? (*b*) Draw station circles showing the following barometer readings: 991.1 mb.; 1022.6 mb.; 1002.0 mb. (*c*) What is an isobar? How are isobars marked on weather maps? What is the difference in pressure between two consecutive isobars? (*d*) Where may isobars be used other than on daily weather maps?

7. (*a*) How does the temperature of the atmosphere affect its pressure? (*b*) Why is humid air lighter than dry air?

8. (*a*) What would be the distribution of air pressure if the surface of the earth were uniform, and if the earth did not rotate? (*b*) With the aid of a labeled diagram, describe the presure belts on the earth. (*c*) Explain why and when pressure belts shift.

9. (*a*) Why are isobars most regular in the Southern Hemisphere south of Africa? (*b*) How does the air pressure over a continent compare with that over the ocean in the same latitude in summer? in winter? Explain why. (*c*) Why are the isobars circular over a continent in summer? in winter? (*d*) Define a low or cyclone; define a high or anticyclone.

10. (*a*) What weather forecast may be made on the basis of a falling barometer reading? a rising barometer reading? Explain why. (*b*) What is a basis for more accurate forecasts than single barometer readings?

11. (*a*) Why must barometer readings be reduced to sea level? (*b*) For approximate reduction to sea level, how much must be added to barometer readings at: (1) Banff; (2) Calgary—3500 feet altitude; (3) Mexico City—7000 feet altitude?

12. (*a*) Define pressure gradient. (*b*) What is meant by a pressure gradient's being steep? gentle? (*c*) How do isobars show a steep pressure gradient? a gentle one?

GENERAL QUESTIONS

1. How high would a barometer tube have to be if water were used instead of mercury?

2. Why must there be a vacuum at the top of the barometer tube?

3. Why is Torricelli's vacuum not a perfect vacuum?

4. In pounds per square inch what is the air pressure (approximate) at 2000 feet? 6000 ft? 3.5 miles?

5. Why should millibars be preferred to inches as units for air pressure?

6. If the 999 mb. isobar is marked 29.50 inches, what is the inch reading on the 996 mb. isobar and the 1002 mb. isobar?

7. Draw a diagram to illustrate the pressure gradients between Winnipeg and Montreal as described in Topic 12.

8. Suppose that Figure 3–13 is drawn on a scale of 1 inch to 500 miles. Calculate the pressure gradient for both the low and the high.

9. How high would the atmosphere be if its density throughout were the same as at sea level? Explain.

10. Verify the statement that air at sea level weighs about 1/800 as much as fresh water. (Fresh water weighs 62.5 pounds per cubic foot.)

11. Why does a radio vacuum tube not collapse under the pressure of the air?

STUDENT ACTIVITIES

1. Reading and recording the air pressure each day
2. Making a graph of the daily pressures for a month
3. Taking care of the barograph
4. Taking an aneroid barometer to the top of a hill, mountain, or tall building to observe the drop in air pressure (or into a mine or cave to observe the rise in pressure)
5. Using the barometer to measure the height of a building
6. Setting up a mercury barometer
7. Setting up a "water barometer"

SUPPLEMENTARY TOPICS

1. Air Pressure in the Stratosphere
2. Other "Barometers"
3. The Fortin Barometer
4. The Density of Oxygen, Nitrogen, and Water Vapor
5. Barometer Readings in World Pressure Belts
6. The Millibar
7. Record Barometer Readings
8. Altimeters

See list of suggestions for further reading at the end of Chapter 1.

Chapter 4

THE ATMOSPHERE'S CHANGING WINDS

Introduction. The air of the earth's atmosphere travels about under many names and in a variety of characters. As a *calm,* it stands so still that it barely disturbs a column of smoke rising from a chimney. Then it moves ever so gently, and we poetically name it a *zephyr.* It blows in from the ocean to break the sultry heat of a summer's day, and we welcome it as a *breeze.* Its speed increases, and it becomes a *wind,* a *gale,* a *hurricane.* But this hardly completes the list of names. In North America there are also the cold wet *northeaster,* the raging *blizzard,* the whirling *tornado,* and the snow-eating *chinook.* Southern France has its cold *mistral,* the Adriatic its fierce *bora,* Spain its hot dry *solano.* The Alps have their chinook-like *foehns,* and Russia has its blizzard-like *buran.* Egypt has its scorching *khamsin,* Argentina its chilly *pampero,* Australia its blistering *brickfelder,* India its changing *monsoons,* and Patagonia its wild avalanching *williwaws.*

The wind blows into every corner of the earth's surface. What makes it blow? What makes it blow hot, blow cold, blow gently, blow violently? Where does it start? Where does it go to? How high does it reach?

1. How winds originate. We have already seen how unequal heating of the earth's surface by the sun causes convectional rising of air in the more highly heated areas. These areas become regions of low air pressure. Cooler areas become regions of high air pressure, where air descends and then moves into the low pressure areas. If the earth were not rotating, we should find that *air moved from regions of higher pressure toward regions of lower pressure.* Movements of air more or less parallel to the surface are called *winds,* while vertical up or down movements, such as those that exist at the center of a convectional system, are usually called *currents.*

Winds vary in strength, and it is found that when pressure gradients are steep, winds are strong; when pressure gradients are gentle, winds are weak; when the pressure gradients are very small, there may be no wind blowing at all and *calms* exist.

To summarize, winds blow from regions of higher air pressure toward regions of lower air pressure. The steeper the pressure gradient the stronger the wind. (Isobars close together show steep pressure gradients.) Figure 4–1 shows how the winds might blow out of a

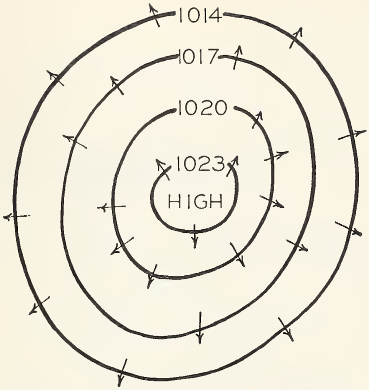


Fig. 4–1. Winds always blow from areas of high air pressure to areas of low air pressure. (In this diagram the effect of the earth's rotation is not considered.) The winds are represented by arrows.

high-pressure area from the highest pressure at the center toward the lower pressures all around it.

2. Effect of the earth's rotation. If the earth did not rotate on its axis, winds would probably move directly from high pressure to low pressure, perpendicular to the isobars, as shown in Figure 4–1. But it has long been known that they do not move that way. Instead, they move at a decided angle to the isobars, often as much as 60 degrees from the perpendicular, and even more in the upper air. That this deflection is due to the earth's rotation was first shown mathematically in 1856 by the American mathematician and teacher William Ferrel. Ferrel's Law states that *because of the earth's rotation Northern Hemisphere winds are deflected to their right, and Southern Hemisphere winds to their left.* In applying Ferrel's Law: (1) Lightly draw an arrow to represent the wind direction from high pressure to low pressure. (2) *Look* in the direction of the arrow, even if it means turning your paper upside down. (3) Draw a second, heavy arrow leading to the right (left in the Southern Hemisphere) of the first arrow. Erase the first arrow. Figure 4–2 shows winds drawn in accordance with these rules.

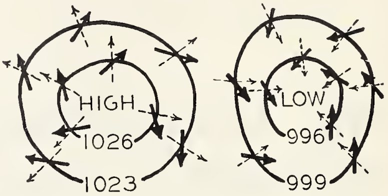


Fig. 4–2. How winds actually blow in the Northern Hemisphere (solid arrows), because of the rotation of the earth as explained by Ferrel's Law. See Topic 2.

The earth's rotation affects all winds, regardless of their direction, with one exception: winds blowing along the Equator are not deflected to right or left.

3. Demonstrating Ferrel's Law. Ferrel's Law may be demonstrated on a slowly rotating turntable or slate globe. As the globe rotates slowly in a vertical position from west to east, fairly thick white water-color paint is poured or squirted from a medicine dropper in a thin stream onto the North Pole. As the stream runs down the Northern Hemisphere it swerves to the right, but as soon as it crosses the Equator it swerves sharply to the left.

4. Naming winds. How are winds named? The answer can easily be derived by considering a few familiar illustrations. North winds are usually cold winds because they come from the cold north. South winds are warm because they come from the warm south. A sea breeze is damp and salty because it comes from the sea. Obviously, then, *winds are named for the direction from which they come.*

Windward means the direction from

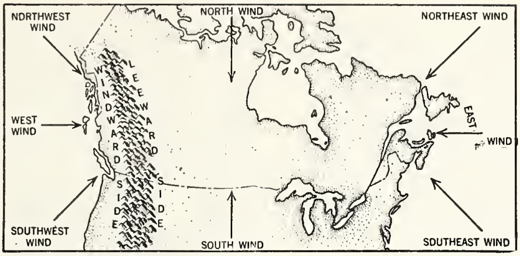


Fig. 4–3. Winds are usually given the name of the direction from which they originate.

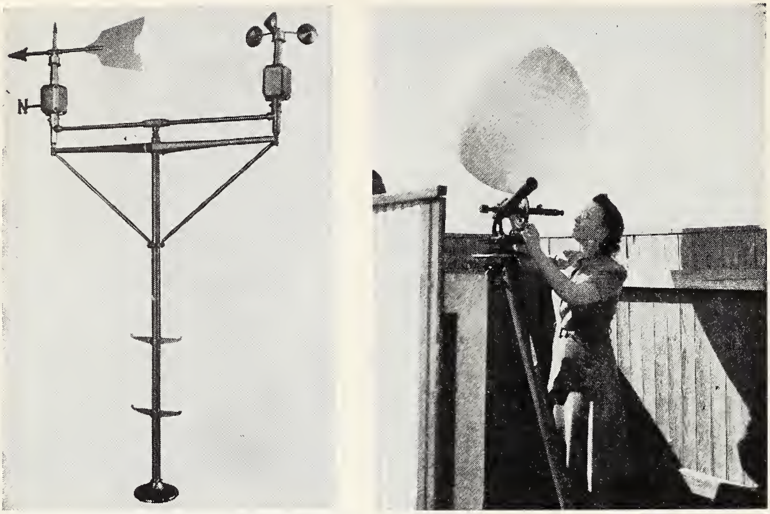
which the wind is coming; *leeward* is the direction toward which it blows. If a wind from the west is blowing across the Rocky Mountains, the western side of the Rockies is the windward side, and the eastern side is the leeward side.

5. Wind direction and weather. There is usually a very definite relation between the direction of the wind and the weather. Winds from a northerly direction (north, northeast, or northwest) are coming from generally cooler latitudes and are likely to bring cool or cold weather. Winds from a southerly direction come from warmer latitudes and bring warm or hot weather. Exactly the reverse is true in the Southern Hemisphere, where south winds are cold and north winds are warm. Winds from the sea carry large amounts of water vapor and may therefore bring clouds and rain. Winds from the interior, on the other hand, are much drier and usually bring relatively clear weather. Along the Atlantic coast of the Maritimes east winds from the Atlantic are generally the moist winds, and west winds from the interior are the dry ones. On the Pacific coast the opposite is true.

6. Observing wind direction and speed. The direction of the wind is usually determined by the use of the familiar weather vane, more accurately called a *wind vane.* This instrument points *into the wind,* or to windward—the direction from which the wind is blowing. For example, a wind vane pointing to the south shows a south wind. The wind vane has a broad "tail" which offers much more resistance to the wind than the slender arrowhead end. A south wind swings the tail toward the north, causing the arrowhead to point to the south. At weather stations, the wind vane is connected by wires to an electrical indicator in the main office. At airports, *wind socks* serve as very large and plainly visible wind-direction indicators for pilots.

Wind speed is measured by the *anemometer* (an uh *mom* uh ter). There are many kinds of anemometers, but the Robinson three-cup anemometer (*anemo,* wind; *meter,* measure) shown in Figure 4–4*a* is the one used by most weather bureaus. The cups are hollow hemispheres, all facing the same way, which catch the wind on their open sides, no matter what the wind direction. The stronger the wind, the faster the cups turn, and the higher the reading of the instrument. The speed is given in miles per hour.

The speed and direction of upper-air winds may be determined with the help of *pilot balloons,* which, when filled with hydrogen or helium, have a diameter of between two and three feet. A balloon is released into the air, and then its flight is followed either by radar or through a telescopic instrument called



Courtesy U.S. Weather Bureau

Courtesy U.S. Weather Bureau

Fig. 4–4. (*a*) Wind instrument support with standard 3-cup anemometer and wind vane indicating a north wind. (*b*) The observer is about to release a pilot balloon and follow its flight with the theodolite.

a *theodolite* (thee *odd* uh lyte). The balloon rises at a fairly constant speed of about 600 feet per minute, and from its angle of flight both the direction and the speed of the upper winds can be calculated by trigonometry. (At night a small lantern is hung from the pilot balloon.)

Wind speed increases with altitude, since the effect of friction between the air and the ground decreases. Wind speeds are also generally greater in winter than in summer, because of the steeper pressure gradients that exist in winter; and they are greater over water than over land, because of the smoother surfaces.

7. Gusts. Winds are rarely steady. Instead they often blow in spurts called *gusts*, die down briefly, and then blow gustily again. Even the direction of the wind varies from moment to moment, although maintaining one general course. These variations in speed and direction are due principally to the irregularities and obstacles of the surface over which the wind travels. Over a smooth surface, such as an ocean, winds are much steadier than over rough land surfaces.

8. Winds on maps. *Wind directions* are shown on maps by arrows that "fly with the wind," as already shown in

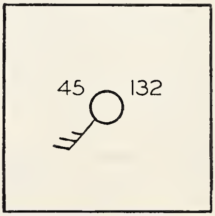


Fig. 4–5. Station model showing a temperature of 45° F, a pressure of 1013.2 mb. and a southwest wind of 25 knots.

Figure 4–3. *Wind speeds* are indicated by *feathers*, or *barbs*, on the left side of the tail of the arrow, according to the velocity of the wind in knots. One barb being equivalent to 10 knots and a half barb to 5 knots. Many weather services still use the *Beaufort Scale* which was introduced by Admiral Beaufort of the Royal Navy in 1805. To save space the head of the arrow is no longer shown on weather maps, the direction of the wind being inferred from the position of the tail. Figure 4–5 shows a station model with a southwest wind of 25 knots. Each full feather counts for a force of 2 in the Beaufort Scale, each half feather for a force of 1. See Figure 4–6.

9. Planetary wind and calm belts. Planetary winds are winds which would be found on any planet that has an atmosphere, that is heated at its equator, and that is rotating on its axis. The earth's planetary winds can easily be

Beaufort Scale of Wind Force

Beaufort number	*Specifications for use on land*	*Miles per hour (statute)*	*Terms used in Canadian Meteorological Service*
0	Calm; smoke rises vertically	Less than 1	Calm.
1	Direction of wind shown by smoke drift, but not by wind vanes.	1–3	Light air.
2	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4–7	Light breeze.
3	Leaves and small twigs in constant motion; wind extends light flag.	8–12	Gentle breeze.
4	Raises dust and loose paper; small branches are moved.	13–18	Moderate breeze.
5	Small trees in leaf begin to sway; crested wavelets form on inland waters.	19–24	Fresh breeze.
6	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	25–31	Strong breeze.
7	Whole trees in motion; inconvenience felt in walking against wind.	32–38	Moderate gale.
8	Breaks twigs off trees; generally impedes progress.	39–46	Fresh gale.
9	Slight structural damage occurs (chimney pots and slate removed).	47–54	Strong gale.
10	Seldom experienced inland; tree uprooted; considerable structural damage occurs.	55–63	Whole gale.
11	Very rarely experienced; accompanied by widespread damage.	64–75	Storm.
12		Above 75	Hurricane.

Fig. 4–6. The Beaufort Scale of wind force, as defined by the Meteorological Service.

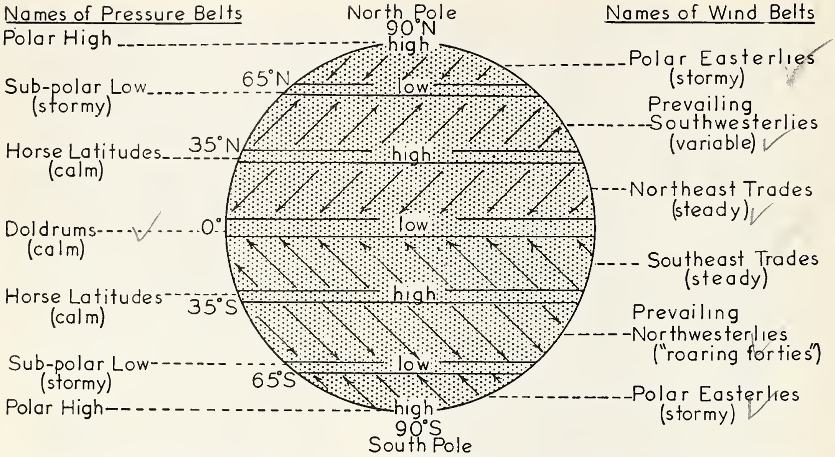


Fig. 4–7. A simplified diagram of the planetary wind and air pressure belts of the earth.

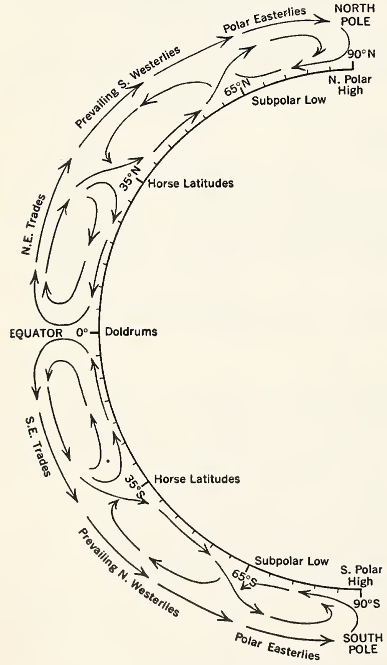


Fig. 4–8. A vertical section through the troposphere from the Equator to the Poles, showing air movement at and above the earth's surface.

drawn by applying the principles learned in Topics 1 and 2 to the idealized diagram of world pressure belts described in the last chapter. Winds must blow from high pressure to low pressure; in the Northern Hemisphere they are deflected to their right, in the Southern Hemisphere to their left. Figure 4–7 shows the earth's planetary winds. Notice that these winds are named for the direction from which they come, as explained in Topic 4. This map of planetary winds is "idealized," as is the pressure map from which it is derived. It represents only the starting point for understanding the wind belts of any planet. For complete accuracy it will be necessary a little later to consider the effect on this general wind system of the highs and lows that form over the unequally heated continent and ocean areas. But first we must understand the general features of the wind system. Figure 4–7 shows the winds at the surface only. To understand wind movements above the surface, a vertical section of the atmosphere from North Pole to South Pole is shown in Figure 4–8.

The doldrums. Heated air rising in

the doldrums or equatorial low-pressure belt makes this area a belt of calms. Much of its air movement is in the nature of *upward* currents with scarcely any horizontal winds. It is therefore a hot belt of low pressure, rising air, light breezes, and frequent calms. In the days of the sailing vessel it was a misfortune to be becalmed in the doldrums, where "the wind blew up the mast."

The horse latitudes. Part of the air that rises in the doldrums comes down in the two belts of the horse latitudes, north and south, to make them belts of high pressure. As in the doldrums, air movement is largely vertical, but *downward*, and so these belts, too, are calm belts. The air is warm but not as warm as in the doldrums.

The trade winds. From the high pressures of the horse latitudes, winds blow in both directions, toward and away from the Equator, to make two of the great wind belts of each hemisphere. The winds blowing toward the Equator are known as the *trade winds.* In the Northern Hemisphere, deflected to their right by the earth's rotation, they become the *northeast trades.* In the Southern Hemisphere, deflected to their left, they are the *southeast trades.* The trade winds are remarkably constant in both direction and velocity, and derive their name from the trade routes charted through them by sailing vessels in earlier times.

The prevailing westerlies. These winds also originate in the high-pressure belts of the horse latitudes and *blow polewards* as far as the subpolar lows. Deflected by the earth's rotation, they are *southwesterlies* in the Northern Hemisphere and *northwesterlies* in the Southern Hemisphere. Unlike the trades, they are highly variable in both strength and direction, and the term "prevailing" merely indicates that they blow from one direction more often than from any other. The strength of the westerlies increases with latitude, and it is greater over the uninterrupted surface of the ocean than over the land. In the almost unbroken ocean area of the Southern Hemisphere beyond South America the violently stormy westerlies are known as the "roaring forties."

The polar easterlies. From the polar highs fiercely cold and violent winds blow into the subpolar low-pressure regions in both hemispheres. These *polar northeasterlies* and *polar southeasterlies* have the same general direction as the trades. Both the polar highs and the subpolar lows are stormy regions.

10. Shifting of the wind belts. In Chapter 3 it was seen that the world pressure belts shift as the sun's vertical rays shift. Since the pressure belts are responsible for the wind belts, the planetary wind system shifts too. The shift averages 5 or 6 degrees of latitude during the entire year; this is equal to a distance of about 350 to 400 miles from north to south. This distance is much less than the distance shifted by the heat equator, and the farthest north and south positions are reached in September and March rather than in July and January. The wind belts and pressure belts are said to "lag" behind the heat equator.

Shifting of the world wind system causes marked weather changes in places that are so located as to be in more than one belt during the year. There are two important cases of this kind. Places near the Equator (such as A in Figure 4–9) may have both doldrums and trades over them during the year. Places in or near the horse latitudes may have both trades and westerlies over them during the year. See *B*, *C*, and *D* in Figure 4–9.

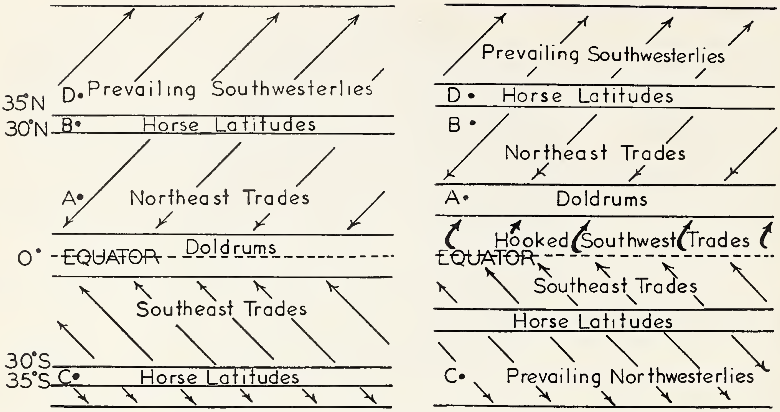


Fig. 4–9. The shifting of wind belts. The diagram at the left shows the planetary wind belts in April when the doldrums belt is at the geographic Equator. The diagram at the right shows them in September, when the doldrums belt is north of the Equator, causing the southeast trades to cross the Equator and become hooked.

Hooked trade winds develop when the doldrums belt into which the trades blow is entirely north or south of the Equator. As the trades cross the Equator, they are subjected to a deflection opposite to that in the hemisphere of their origin; they then become "hooked." For example, when the doldrums belt is entirely north of the Equator, the southeast trades from the Southern Hemisphere must cross the Equator as they go north. When they cross, they are deflected to the right and become southwest trades (see Figure 4–9). Similarly, if the northeast trades cross the Equator, they become hooked northwest trades.

11. Seasonal effect. In winter, when the continents are colder than their neighboring ocean waters, they become centers of high pressure from which winds tend to blow outward to the sea. In summer, the continents are warmer than their neighboring ocean waters, and they become centers of low pressure toward which winds tend to blow from the sea. This change is sometimes known as the *monsoon effect*. It changes the prevailing winds of the belt somewhat

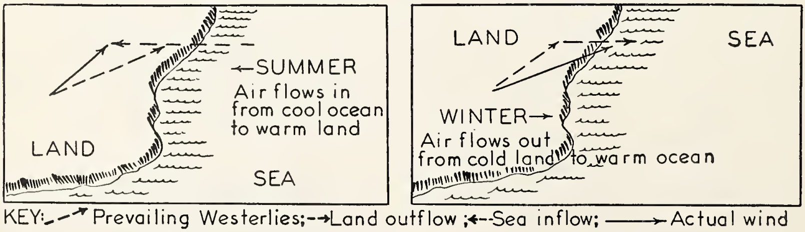

←SUMMER
Air flows in from cool ocean to warm land
LAND
SEA
LAND
SEA
WINTER→
Air flows out from cold land to warm ocean
KEY: Prevailing Westerlies; Land outflow; Sea inflow; Actual wind

Fig. 4–10. The seasonal effect of land and sea on the prevailing winds of northeastern United States.

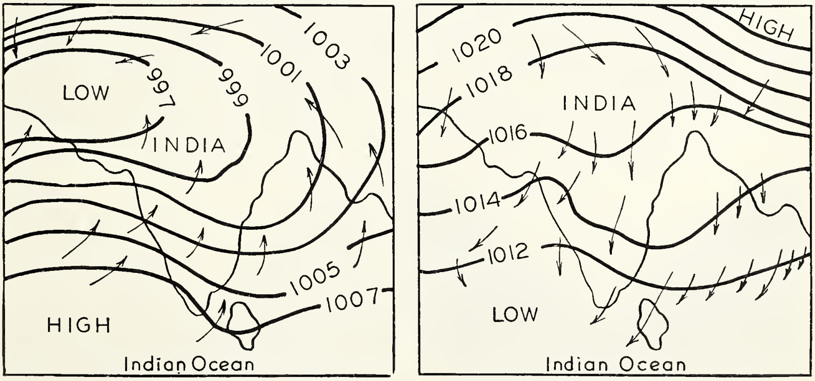
in strength and direction. To illustrate, Figure 4–10 shows how the summer inflow of air along the Atlantic coast weakens the prevailing southwesterlies and makes them more southerly, while the winter outflow from the land strengthens the prevailing southwesterlies and makes them more westerly. On the Pacific coast the reverse is true. The prevailing southwesterlies are strengthened in summer and weakened in winter.

12. Monsoon winds. In parts of the tropics which are covered by two different wind belts during the course of the year, it may happen that the monsoon effect is in exactly the right direction to strengthen each of the wind belts. Since the monsoon effect in summer is just the reverse of that in winter, such regions will have a complete reversal of summer and winter wind directions. The best-developed monsoon winds in the world are found over India, southeast Asia, and the Indian Ocean.

In summer, the hot northern interior of India is in the doldrums, and it forms a great low-pressure center. The relatively cooler Indian Ocean is now a center of high pressure. The *summer monsoon* therefore blows from the ocean to the land, but being deflected to the right according to Ferrel's Law, it becomes largely a southwest wind, corresponding to the hooked trades shown in Figure 4–9. This warm, moist summer monsoon, blowing steadily from the ocean from May through October, brings to India its long rainy season; hence it is often referred to as the *wet monsoon.*

In winter, the cold interiors of India and southern Siberia produce a gigantic high-pressure area from which winds blow southward to the low pressures of the relatively warmer Indian Ocean. Deflected to the right, these winds become northeast winds, exactly opposite in direction to the southwest winds of summer, and forming a part of the normal Northern Hemisphere northeast trade-wind belt (see Figure 4–9). Coming from the cold interior, they bring cold dry weather from November through April, and are called the *dry monsoon* or *winter monsoon.*

Other regions that have monsoons, though not nearly so complete a reversal as in India, are Australia, Spain, and



SUMMER WINTER

Fig. 4–11. The summer or southwest monsoon comes from the Indian Ocean and is warm and rainy. The winter or northeast monsoon comes from the interior and is cold and dry.

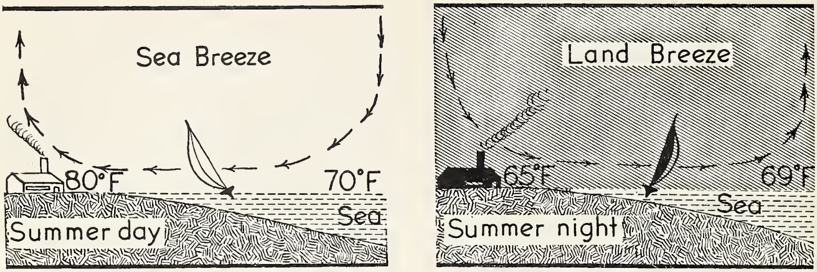


Fig. 4–12. The sea breeze blows during the daytime when the air over the sea is cooler than the air over the land. The land breeze blows at night when conditions are reversed.

Portugal. As with India, the explanation lies in the fact that the peninsula of Spain and Portugal and the island of Australia are largely or entirely surrounded by water and are within the region of shifting tropical wind belts.

13. Land and sea breezes. These breezes often produce changes in wind direction near the sea. During the day, coastal regions warm up more than adjoining waters. The land becomes an area of low pressure, the water an area of high pressure, and a cool breeze blows from water to land. Along seacoasts this *sea breeze* usually begins gently about 11 A.M., increases in velocity until 2 P.M. or 3 P.M., and dies down toward sunset. It is felt inland not more than 10 or 15 miles and extends upward about 1000 feet into the atmosphere.

At night the land usually becomes cooler than the adjoining waters. The land is then an area of high pressure, the water an area of low pressure, and a breeze blows from land to sea. This *land breeze* may start long before midnight and die down toward sunrise. Sea breezes are usually better developed than land breezes; at least they are more noticeable, particularly on hot summer days when they provide a most welcome cooling effect on the near-coastal areas. At the beach they may be so strong as to become a distinct nuisance, and many a bather's day has been spoiled by "too much sea breeze" with its annoying blowing of sand. Similar water and land breezes may develop along lake shores.

14. Mountain and valley breezes. Mountainous regions also have their "daily monsoons." At night, cold heavy air drains down from the mountain tops

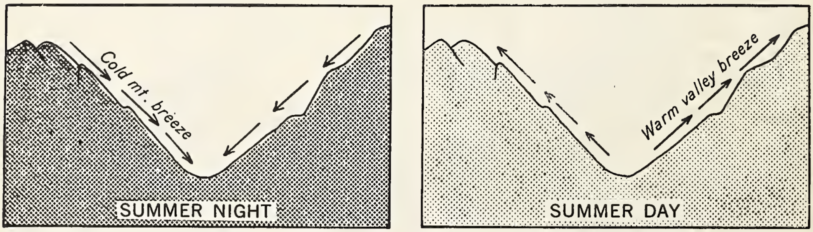


Fig. 4–13. At night cold mountain air sinks into the valleys to form the mountain breeze. During the daytime the valley breeze blows when warm valley air rises toward the mountain tops.

into the valleys below. The narrower the valley, the stronger the breeze is likely to be. Coming from the mountains, it is called the *mountain breeze.* During the daytime, warm air rises convectionally along the sunny mountain slopes from which the air receives most of its heat, and a *valley breeze* blows upslope from the valley. Its velocity is generally much less than that of the downhill mountain breeze.

15. Actual world wind belts. Topics 9 and 10 considered the wind belts as if they were uniformly extended across the entire world in their particular latitudes. Topic 11 explained the monsoon effect of large land masses in winter and summer, while Topic 12 described the monsoon winds of India in detail. Figures 14 and 15 show the world wind and pressure belts as they are actually observed for the months of January and July.

The *doldrums* (into which the trades blow) are seen as a series of lows rather than as a single low-pressure belt. In January these lows are centered over the three continental areas south of the Equator, where the vertical sun is then located. In July the doldrums are mostly north of the Equator, with one great low extending far north into India.

The *trades* are easily identified. On the January map they are almost as regular as in the idealized diagram of Figure 4–7. Northeast trades and southeast trades blow into the doldrums, and only near the west coast of Africa and near Australia do the northeast trades cross the Equator to become *hooked northwest trades.* In July, hooking is conspicuous in the southwest monsoon of India and in Africa.

The *horse latitude* belts, 30° to 35° latitude, are seen to consist of a series of highs. These highs are very definite in the Southern Hemisphere, which is mostly ocean. They are less distinct in the Northern Hemisphere, particularly in July when the heated continents become low-pressure centers.

The *prevailing westerlies,* from the horse latitudes through the temperate zone, are plainly seen in the Southern Hemisphere over the great ocean areas. In the Northern Hemisphere, however, the monsoon effect of continental low pressure in July and high pressure in January makes this belt very much different from the idealized picture.

The *subpolar lows* can be identified as a single belt in latitude 60° to 65° in the Southern Hemisphere, and less distinctly in the Northern Hemisphere in the form of lows near Iceland and Alaska. Blowing into these lows are seen the *polar easterlies* that originate in the *polar highs* over Greenland and Antarctica.

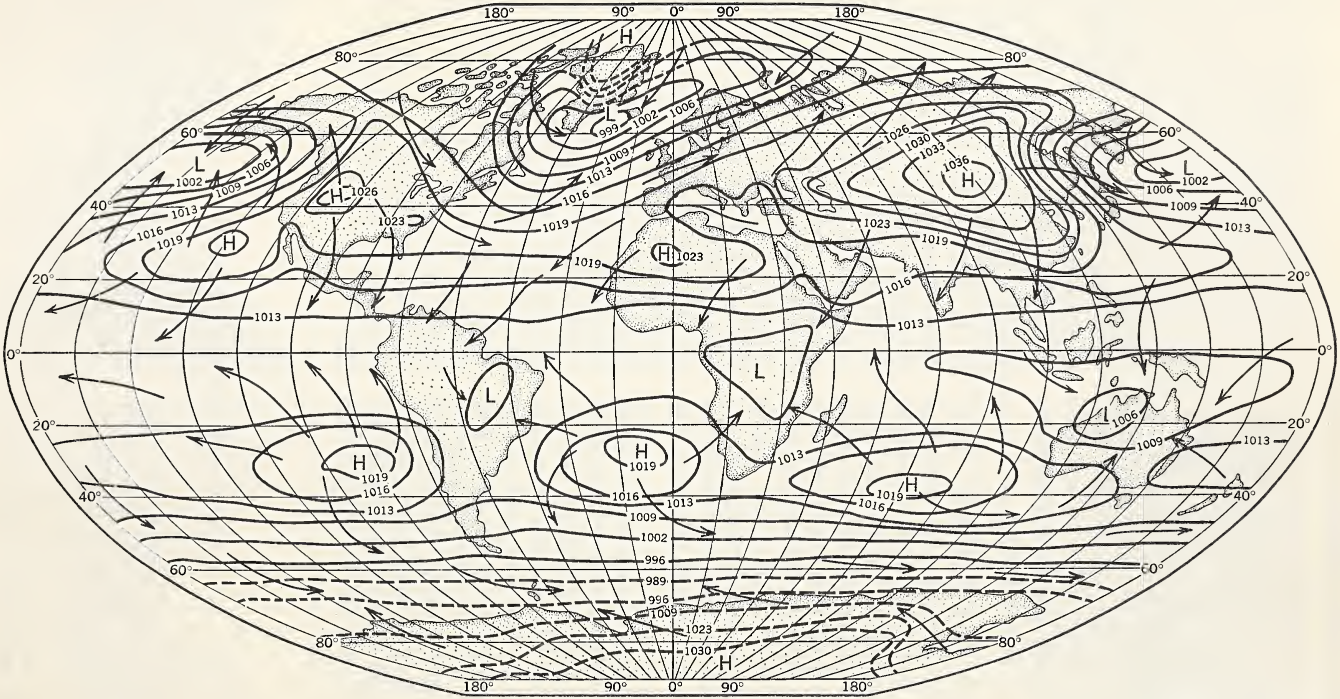
HAVE YOU LEARNED THESE?

Meanings of: wind, current, calm, windward, leeward, wind vane, anemometer, gusts, monsoon effect, monsoon wind, Ferrel's Law, trades, westerlies, polar easterlies

Diagrams and descriptions of: planetary wind, calm, and pressure belts; monsoons of India; land and sea breezes; wind direction and force

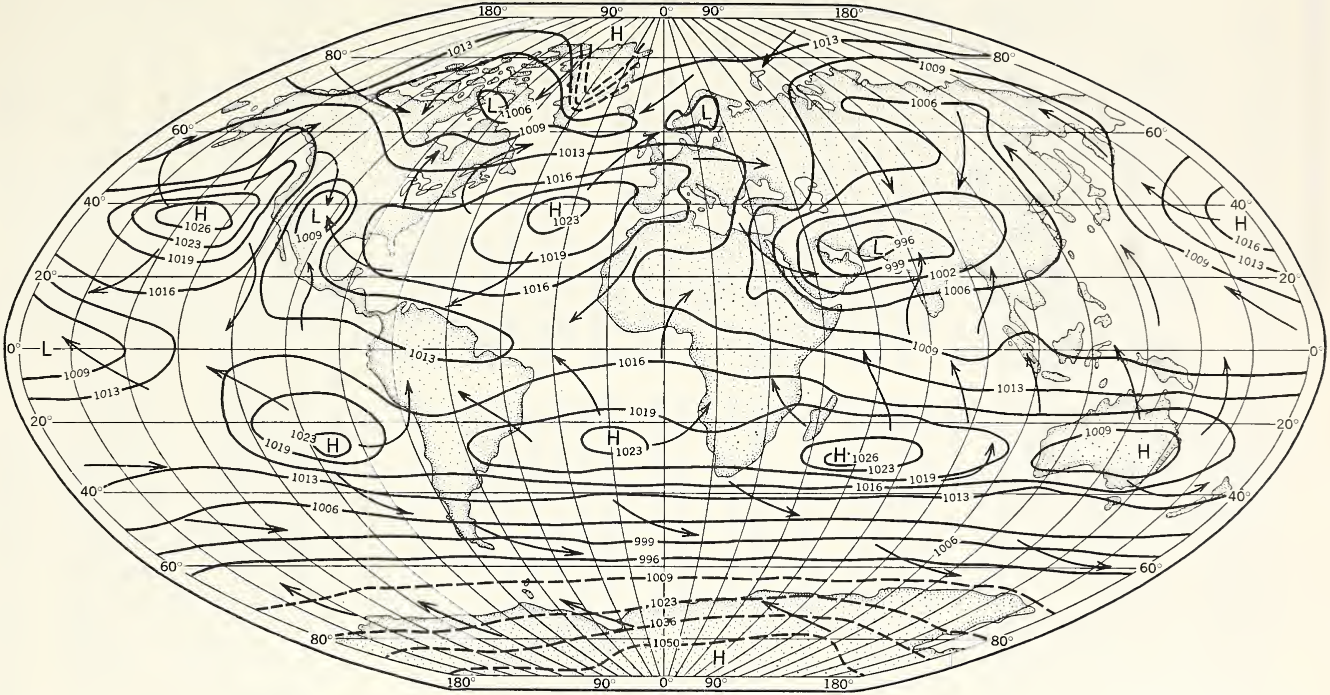
Explanations of: origin of winds; shifting of wind belts; origin of hooked trades; origin of monsoons; origin of land and sea breezes

Relations between: wind direction and



After Finch and Trewartha

Fig. 4–14. World pressure and wind belts for January. Since it is winter in the Northern Hemisphere, the cold land masses of North America and Asia are now centers of high air pressure.



After Finch and Trewartha

Fig. 4–15. World pressure and wind belts for July. It is summer in the Northern Hemisphere. The warm continents of North America and Asia are now centers of low air pressure.

weather; wind speed and pressure gradient; wind speed and altitude; wind speed and season; wind speed and surface; winds and their names; wind direction and pressure; wind direction and the earth's rotation

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) How do winds originate? (*b*) Distinguish between winds and currents. (*c*) What determines whether there will be strong winds, weak winds, or calms? (*d*) How does air pressure determine wind direction?

2. (*a*) What effect does the earth's rotation have on wind directions? (*b*) Copy the high in Figure 4–1, and use Ferrel's Law to figure out the correct wind directions, taking the earth's rotation into account.

3. How can Ferrel's Law be demonstrated?

4. (*a*) Explain how winds are named. (*b*) Distinguish between windward and leeward.

5. What is the relation between wind direction and temperature? wind direction and moisture?

6. (*a*) Explain the action of a wind vane. (*b*) Explain the action of an anemometer. (*c*) How are the speed and direction of the upper air winds observed? (*d*) Why does wind speed increase with altitude? (*e*) Why are winter winds stronger on the average than summer winds?

7. Explain what gusts are and how they form.

8. Draw symbols to show the following winds: (1) west, force 7; (2) a calm; (3) southeast, force 2; (4) northwest, force 5; (5) northeast, force 8. Give the speed of each wind in miles per hour, and explain how such wind force can be recognized without an anemometer.

9. (*a*) Work out and reproduce the diagram of the earth's planetary wind and calm belts. Learn it. (*b*) Give a brief description of each wind and calm belt.

10. (*a*) Why and how much do the wind belts shift? (*b*) Where do shifting wind belts cause weather changes? (*c*) Explain how hooked trade winds develop.

11. Explain what is meant by the monsoon effect.

12. With the aid of simple sketches explain the origin of the summer and winter monsoons of India and their weather characteristics.

13. Describe the origin and characteristics of sea breezes and land breezes.

14. Explain the origin of mountain and valley breezes.

15. Explain the actual appearance of the world pressure and wind belts as shown on the maps of Figures 4–14 and 4–15.

GENERAL QUESTIONS

1. What are the probable temperature and moisture characteristics of north, south, east, and west winds in: (1) St. John, N. B., (2) New Orleans, (3) Winnipeg, (4) Yellowknife, (5) Buenos Aires, (6) Sydney, Australia?

2. Make a diagram (similar to that in Figure 4–9) showing how hooked northwest trade winds develop when the doldrums are south of the Equator in February.

3. Make a diagram showing the monsoons of India.

4. Make a diagram to show the probable summer and winter monsoon winds of Australia. Compare your diagrams with actual conditions shown in the maps of Figures 4–14 and 4–15.

5. What parts of Africa show marked monsoon changes of winds? See Figures 4–14 and 4–15.

6. On what time schedule might a fishing fleet of sailing vessels make best use of land and sea breezes?

7. Why does the low near Iceland persist even in summer, when the ocean should be cooler than the adjoining land?

STUDENT ACTIVITIES

1. Constructing a Wind Vane
2. Constructing an Anemometer
3. Making daily observations of wind direction and velocity from instruments
4. Keeping and plotting a daily record of wind direction and velocity
5. Visiting an airport or weather bureau station to observe wind instruments
6. Demonstrating Ferrel's Law

SUPPLEMENTARY TOPICS

1. Ferrel's Law; Explanation
2. Upper Air Winds and Pressures
3. Wind Vane Construction
4. Anemometers; Other Types
5. Electrically Indicating Wind Instruments
6. The Theodolite and Its Use
7. Gusts, Wind Eddies, Turbulence
8. Origin of the Beaufort Scale
9. Winds on Other Planets
10. Why the "Horse" Latitudes?
11. Polar Winds
12. Winds of Other Countries (as named in the "Introduction")
13. Record and Average Winds in Canada

See list of suggestions for further reading at the end of Chapter 1.

Chapter 5

WATER VAPOR ENTERS THE ATMOSPHERE

1. Water vapor and evaporation. A swimmer climbs out of the pool and chats with his teammate; wet laundry hangs on a line or tumbles about in an automatic dryer; grass sparkling with dew meets the rays of the morning sun. In time, all these wet objects become dry. The water that was on them has been transformed into *water vapor*—water in its invisible gaseous state—and has literally disappeared into thin air. This change from water into water vapor is called *evaporation*. Evaporation is brought about by heat which comes from outside sources like the sun or from materials in contact with the water, like the bather's body. Evaporation is a cooling process, for it takes place at the expense of the heat of its surroundings. The bather whose body heat is being used to evaporate the water that is on him may shiver until he dries out. A fevered patient may be cooled by the rapid evaporation of alcohol from his forehead. An electric refrigerator is chilled by the extremely rapid evaporation of liquid ammonia or other refrigerants in its coils.

The *rate at which water evaporates* into the air depends upon both the water and the air. The warmer the water is and the larger its surface, the faster it evaporates. The warmer the air, the drier it is, the lower its pressure, and the windier it is, the faster will it cause water to evaporate. Clothes on a line will dry most rapidly if well spread out and still warm, on a day when the air is dry, the air pressure low, the sun strong, and a good breeze is blowing.

2. Sources and distribution of water vapor. Water vapor enters the air from any place on the earth's surface where water exists either as a liquid or as ice. Ice evaporates too, though more slowly than water because it is colder. Most of the water vapor in the atmosphere comes from the oceans, lakes, marshes, and glaciers that comprise about three-fourths of the earth's surface, but additional amounts are supplied by moist ground and by plant and animal breathing. Water vapor is most abundant near the surfaces from which it arises, although it is distributed throughout the troposphere by convection and winds, and may be carried a thousand miles inland from the oceans. Since convection ends at the tropopause, there is practically no water vapor in the stratosphere.

3. Capacity and saturation. *Humidity* (hue *mid* itee) is a term used generally to refer to the moisture condition of the atmosphere. For specific references to atmospheric moisture meteorologists use the terms "capacity," "absolute humidity," and "relative humidity," which have definite numerical meanings. The ability of air to hold water vapor depends almost entirely on its temperature. The warmer the air is, the more water vapor it can hold. For each temperature there is a definite limit to the amount of water vapor that can be evaporated into a given volume of air. This amount is called its *capacity*, and may be expressed in *grains of water vapor per cubic foot of air.* To repeat, capacity is the most water vapor that a given volume of air *can* hold at a particular temperature. The higher the temperature the higher the capacity. Air that is filled to capacity is said to be *saturated.* The air between the water and the glass cover of a fish tank is an example of saturated air. The drops of water hanging from the underside of the glass show that while water continues to evaporate from the warm tank, an equal amount of water must leave the already saturated air.

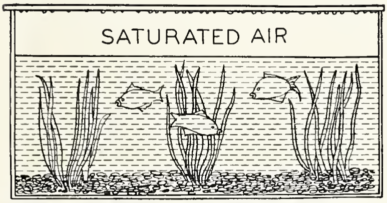


Fig. 5–1. The air in a sealed fish tank is saturated with water vapor.

The following table shows, in round numbers, what the capacity of air is at various temperatures. Remember that a cubic foot of air at room temperature weighs about 1.2 ounces or 500 grains. (It takes about 400 grains to make an ounce.)

Capacity of Air (Approximate)
Grains of Water Vapor per Cubic Foot of Air

Temperature Degrees F	*Water Vapor Grains per cu. ft.*
10°	0.8
20°	1.3
30°	2.0
40°	3.0
50°	4.0
60°	6.0
70°	8.0
80°	11.0
90°	15.0
100°	20.0

4. Absolute humidity and relative humidity. *Absolute humidity* is the amount of water vapor actually present in a given volume of air. Like capacity, it is usually expressed in grains of water vapor per cubic foot of air, and so it can readily be compared with the capacity. In fact, it is this comparison that is of greatest interest to the meteorologist, for he wishes to know to what extent of capacity the air is filled with water vapor.

Relative humidity is the ratio of the absolute humidity to the capacity at any given time. It is always expressed as a per cent, and can be defined and worked out as follows: (R.H. means relative humidity; A.H. means absolute humidity; Cap. means capacity.)

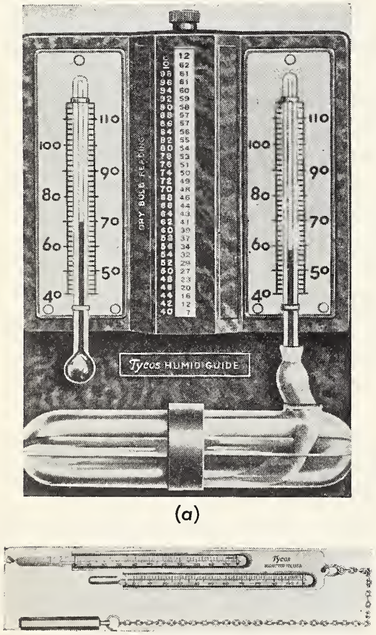
$$\%\ \text{R.H.} = \frac{\text{A.H.}}{\text{Cap.}} \times 100$$

For example, if the absolute humidity is 2 grains per cubic foot, and the air temperature is 60° F, the relative humidity is easily calculated. The capacity table shows that at 60° F a cubic foot of air can hold 6 grains of water vapor. Then,

$$\begin{aligned}\%\ \text{R.H.} &= \frac{\text{A.H.}}{\text{Cap.}} \times 100\\ &= \frac{2\text{g}}{6\text{g}} \times 100 = 33\tfrac{1}{3}\%\end{aligned}$$

5. Finding relative humidity. Instruments used to measure relative humidity are called *hygrometers* (hy *grom* uh ter). In the *hair hygrometer* (*hygro*, moisture; *meter*, measure) changes in the length of a bundle of human hairs cause a pointer to move over a scale from which the relative humidity is read directly in per cent. Human hair is very sensitive to changes in the moisture content of the air, contracting in dry air and lengthening in humid air. The *hygrograph* is merely a hygrometer, a pen, and a rotating record sheet, as in the barograph and thermograph. It makes a continuous record of the relative humidity.

Another form of hygrometer is known as the *psychrometer* (sy *krom* uh ter) or *wet-bulb and dry-bulb thermometer.* It works on the principle that evaporation causes cooling, and dry air causes more rapid evaporation than moist air, as explained in Topic 1. The instrument, shown in Figure 5–2, consists of two identical thermometers, one of which has a water-soaked wick wrapped around its bulb. The air is forced past the two bulbs by fanning or whirling the thermometers. The dry-bulb thermometer simply shows the air temperature; the wet-bulb thermometer usually shows a lower temperature because as water evaporates from its wick, heat is taken from its bulb. *The drier the air the faster the rate of evaporation and the lower the reading of the wet bulb.* So far the instrument shows nothing but two thermometer readings which give some indication of how dry the air is, but no actual relative humidity readings. With the observed thermometer readings the *relative humidity* can be found from a table which has been carefully drawn up on the basis of many experiments, and whose percentages are much more accurate than those of a hair hygrometer.



(a)

(b)

Courtesy Taylor Instrument Companies

Fig. 5–2. Two forms of the hygrometer: (*a*) a stationary wet-bulb and dry-bulb thermometer which must be fanned; (*b*) a sling psychrometer which can be whirled around by the handle and chain shown.

A section of a table used with the psychrometer is given below. Suppose the dry-bulb reading is 70° F and the wet-bulb reading is 63° F—seven degrees lower. First find 70° F in the "Air Temperature" column. Then find 7 in the "Difference in degrees" line. At the intersection of 70° F and 7 the number 68 is the relative humidity in per cent. If both wet-bulb and dry-bulb thermometer read the same, it means that no evaporation has taken place because the air is saturated. The relative humidity at saturation is 100 per cent.

6. Variations in humidity. *Absolute humidity*, the weight of water vapor in a cubic foot of air, varies in a very sim-

TABLE: FINDING RELATIVE HUMIDITY IN PER CENT

Difference in degrees between wet-bulb and dry-bulb thermometers.

Air Temperature (reading of dry-bulb thermometer) in degrees Fahrenheit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30°	89	78	68	57	47	37	27	17	8																					
32°	90	79	69	60	50	41	31	22	13	4																				
34°	90	81	72	62	53	44	35	27	18	9	1																			
36°	91	82	73	65	56	48	39	31	23	14	6																			
38°	91	83	75	67	59	51	43	35	27	19	12	4																		
40°	92	84	76	68	61	53	46	38	31	23	16	9	2																	
42°	92	85	77	70	62	55	48	41	34	28	21	14	7																	
44°	93	85	78	71	64	57	51	44	37	31	24	18	12	5																
46°	93	86	79	72	65	59	53	46	40	34	28	22	16	10	4															
48°	93	87	80	73	67	60	54	48	42	36	31	25	19	14	8	3														
50°	93	87	81	74	68	62	56	50	44	39	33	28	22	17	12	7	2													
52°	94	88	81	75	69	63	58	52	46	41	36	30	25	20	15	10	6													
54°	94	88	82	76	70	65	59	54	48	43	38	33	28	23	18	14	9	5												
56°	94	88	82	77	71	66	61	55	50	45	40	35	31	26	21	17	12	8	4											
58°	94	89	83	77	72	67	62	57	52	47	42	38	33	28	24	20	15	11	7	3										
60°	94	89	84	78	73	68	63	58	53	49	44	40	35	31	27	22	18	14	10	6	2									
62°	94	89	84	79	74	69	64	60	55	50	46	41	37	33	29	25	21	17	13	9	6	2								
64°	95	90	85	79	75	70	66	61	56	52	48	43	39	35	31	27	23	20	16	12	9	5	2							
66°	95	90	85	80	76	71	66	62	58	53	49	45	41	37	33	29	26	22	18	15	11	8	5	1						
68°	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	31	28	24	21	17	14	11	8	4	1					
70°	95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33	30	26	23	20	17	13	10	7	4	1				
72°	95	91	86	82	78	73	69	65	61	57	53	49	46	42	39	35	32	28	25	22	19	16	13	10	7	4	1			
74°	95	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34	30	27	24	21	18	15	12	9	7	4	1		
76°	96	91	87	83	78	74	70	67	63	59	55	52	48	45	42	38	35	32	29	26	23	20	17	14	12	9	6	4	1	
78°	96	91	87	83	79	75	71	67	64	60	57	53	50	46	43	40	37	34	31	28	25	22	19	16	14	11	9	6	4	1
80°	96	91	87	83	79	76	72	68	64	61	57	54	51	47	44	41	38	35	32	29	27	24	21	18	16	13	11	8	6	4
82°	96	91	87	83	79	76	72	69	65	62	58	55	52	49	46	43	40	37	34	31	28	25	23	20	18	15	13	10	8	6
84°	96	92	88	84	80	77	73	70	66	63	59	56	53	50	47	44	41	38	35	32	30	27	25	22	20	17	15	12	10	8
86°	96	92	88	84	80	77	73	70	66	63	60	57	54	51	48	45	42	39	37	34	31	29	26	24	21	19	17	14	12	10
88°	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46	43	41	38	35	33	30	28	25	23	21	18	16	14	12
90°	96	92	88	85	81	78	74	71	68	64	61	58	56	53	50	47	44	42	39	37	34	32	29	27	24	22	20	18	16	14

ple way. It is usually greater over water than over land because water vapor comes from the water. It is greater in warm regions than in cold regions because warm air can evaporate more water and hold more water vapor. For the same reason the absolute humidity is greater in summer than in winter, greater by day than by night, and greater in the lower air than in the upper air.

Relative humidity, the *ratio* of absolute humidity to capacity, does not vary quite as simply. If absolute humidity stays the same while capacity increases, the relative humidity decreases. This may happen when air warms up, since the warmer air is, the greater its capacity. On the other hand, if absolute humidity stays the same while capacity decreases, the relative humidity increases. This may happen when air gets cooler, since the cooler it is, the smaller its capacity. Relative humidity usually decreases during the day as the air warms up in the sun. Although more water vapor usually enters the air too as it warms up, the increase in water vapor never keeps up with the increase in capacity. Relative humidity increases at night as the air cools off and its capacity is reduced. Relative humidity is very low in desert areas, although even there it increases markedly at night. Over oceans relative humidity is consistently high.

7. Condensation and dew point. The change from invisible water vapor to visible water or ice is called *condensation.* It is the opposite of evaporation. When water evaporates, it removes heat from its surroundings. When water vapor condenses, it returns heat to its surroundings. While rapidly evaporating liquids are used to remove heat in refrigerators, rapidly condensing hot-water vapors (steam) are used to give off heat in steam-heating units.

Theoretically, condensation of water vapor in the atmosphere may take place because of continuing evaporation, as in the fish tank referred to in Topic 3. But the atmosphere rarely has a "cover" over it, so condensation rarely occurs in this way. How condensation comes about is best first explained by an illustration. Suppose that on a sunny spring afternoon the air temperature is 60° F and the absolute humidity is 4 grains. The capacity table in Topic 3 shows that each cubic foot of air at 60° F is capable of holding 6 grains of water vapor, so the air is far from saturated. But at night, under clear skies, the air cools rapidly. When it reaches 50° F, it will be saturated, for at 50° F it can hold exactly what it already has—4 grains. If the temperature goes below 50° F, the air will have to release all the water vapor in excess of its capacity. For example, at 40° F its capacity is 3 grains, so each cubic foot of air would have to release 1 grain of water vapor. This released water vapor condenses into visible water, perhaps as dew on the grass, mist over the ground, or droplets in a cloud.

The temperature at which saturation occurs is called the *dew point.* In the illustration given above, the dew point is 50° F, but it may be any temperature, and it depends on one factor alone—the absolute humidity. The more water vapor present in the air, the higher the dew point; the less water vapor, the lower the dew point. For example, an absolute humidity of 2 grains means a 30° F dew point; 15 grains, a 90° F dew point. *Condensation of water vapor takes place when air is cooled below its dew point.* The dew point may also be defined as the temperature below which the air must be cooled before condensation can begin. In defining dew point, the word "temperature" must always be included.

8. Dew-point determination. As was just pointed out in Topic 7, if the absolute humidity is known, the dew point can be found directly from a capacity table. The reverse is also true. If the dew point is known, the absolute humidity can be found in the capacity table. For example, if the dew point is 40° F, the absolute humidity must be 3 grains per cubic foot.

The dew point of the air can be found in exactly the manner indicated by its definition (see Figure 5–3). A sample of air is cooled until its water vapor just begins to condense. The temperature

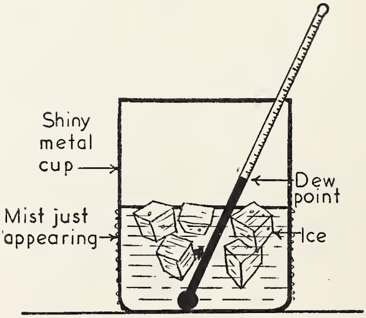


Fig. 5–3. Finding the dew point of the air—the temperature below which condensation begins.

of the air at this moment is its dew point. The cooling is done by a mixture of water and ice in a shiny metal cup, and the air sample being cooled is the air that touches the cup on its outside. When mist forms on the outside of the can, it shows that water vapor is condensing. This is exactly what happens on the outside of a dish of ice cream or a pitcher of ice water.

9. Dew point on the weather map. Neither absolute humidity nor relative humidity is shown on the weather map, although the relative humidity is always given in weather reports. On the other hand, the dew point is shown in the station model, below the temperature. When the dew point is much lower than the air temperature, it means low relative humidity and little likelihood of condensation. On the other hand, when the dew point is only a few degrees below the air temperature, there is a strong probability that fog or clouds will form shortly.

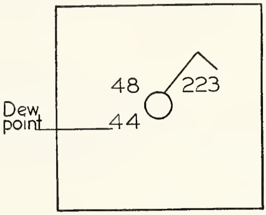


Fig. 5–4. Station model showing temperature, pressure, wind direction, wind velocity, and dew point.

HAVE YOU LEARNED THESE?

Meanings of: water vapor, evaporation, absolute humidity, capacity, relative humidity, saturation, dew point, condensation, hygrometer

Diagrams: dew point on the weather map

Explanations of: finding the dew point; finding the relative humidity; how condensation occurs; how a hygrometer works

Relations between: capacity and air temperature; absolute humidity and dew point; absolute humidity, relative humidity, and time of day; rate of evaporation and atmospheric conditions; dew point and the weather forecast

Expressing: capacity; absolute humidity; relative humidity; dew point

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is evaporation? what is water vapor? (*b*) Give illustrations to show that evaporation is a process that removes heat. (*c*) What conditions determine the rate of evaporation?

2. (*a*) What are the sources of water vapor in the atmosphere? (*b*) How is water vapor spread throughout the troposphere? Why is there almost none in the stratosphere?

3. (*a*) What is the meaning of capacity in reference to the humidity of the air? (*b*) What is the relation between capacity and temperature? (*c*) In what terms is capacity expressed? (*d*) When is air said to be saturated? (*e*) What is the air's capacity at 30° F? 70° F? 100° F?

4. (*a*) What is absolute humidity? How is it expressed? (*b*) Define relative humidity. How is it expressed? (*c*) If the absolute humidity is 4 and the air temperature is 70° F, what is the relative humidity?

5. (*a*) What is a hygrometer? a hygrograph? (*b*) How does the hair hygrometer show the relative humidity? (*c*) In the psychrometer what does the dry-bulb thermometer show? Why does the wet-bulb usually give a lower reading? What determines how much lower? (*d*) Explain how to use the psychrometer in determining relative humidity. Make up an example to illustrate the method.

6. (*a*) How does absolute humidity

vary with location, season, and time of day? (*b*) Why does relative humidity decrease during a sunny day? Why does it increase during the night?

7. (*a*) What is condensation? (*b*) Why is heat given off during condensation? (*c*) What causes condensation to occur in the atmosphere? (*d*) What is the dew point? (*e*) What one factor does the dew point depend upon? Explain. (*f*) What is the dew point when the absolute humidity is 6? 11? 20?

8. Describe an experiment used to determine the dew point.

9. (*a*) Read all the weather data given in the station model of Figure 5–4. (*b*) Draw a station model showing northwest wind of force 6, temperature 53° F, dew point 41° F, barometer reading 1011.7 mb.

GENERAL QUESTIONS

1. Which contains more water vapor: Sahara Desert air at 100° F with a relative humidity of 20 per cent, or saturated arctic air at 10° F. Why?

2. Make a table showing the water-vapor capacity of the air at 30° F, 50° F, 70° F, and 90° F. Roughly, what is the numerical relationship between an increase in temperature and an increase in capacity?

3. What is the absolute humidity when the dew point is 10° F? 40° F? 90° F?

4. Why should a psychrometer be fanned or whirled to get an accurate reading?

5. How can a single thermometer be used to obtain the relative humidity?

6. How many degrees must the air be cooled in order that dew may form if its temperature is 70° F and its relative humidity is 50 per cent?

7. The dry bulb reads 50° F, the wet bulb 40° F. What is the relative humidity?

STUDENT ACTIVITIES

1. Determining the Dew Point by Experiment
2. Determining the Relative Humidity by Use of the Wet-bulb and Dry-bulb Thermometer
3. Plotting a Graph of Relative Humidity from Hour to Hour
4. Calculating Dew Point from Reports of Relative Humidity
5. Making a Chemical Hygrometer or a Hair Hygrometer
6. Measuring the Cooling Effect of Volatile Liquids on the Wet-bulb Thermometer

SUPPLEMENTARY TOPICS

1. Heat of Vaporization at Various Temperatures
2. Refrigerants and Refrigerators
3. World Variations in Relative and Absolute Humidity
4. Specific Humidity and Mixing Ratio
5. The Whirling Psychrometer
6. Heat Released by Condensation at Various Temperatures
7. The Weather Witch
8. Hygrometric Chemicals
9. Freezing by Evaporation

See list of suggestions for further reading at the end of Chapter 1.

Chapter 6

WATER VAPOR CONDENSES OUT OF THE ATMOSPHERE

1. Condensation of water vapor. The invisible moisture of the atmosphere is restored to visibility in a variety of ways and a variety of forms. As a liquid, it may appear in the form of dew, fog, or water cloud. As a solid, it may appear in the form of frost, snow, sleet, or hail. But however it appears, the process by which the water vapor condenses is always the same in one essential. *In order for water vapor to condense, the air must be cooled below its dew point.*

The form in which the water vapor condenses is determined by the conditions under which the cooling occurs. In the atmosphere there are four important processes, any one of which may cool air below its dew point: (1) loss of its heat by radiation; (2) contact with colder surfaces, such as icebergs, layers of snow, the ground, or leaves of plants; (3) mixing with colder air; (4) adiabatic cooling by expansion in rising air currents. See Chapter 2, Topic 16.

2. Dew and frost. When the air is cooled below its dew point by contact with a colder surface, water vapor condenses directly on that surface. If the temperature at which condensation is taking place is above 32° F or 0° C, drops of water called *dew* will form on the colder surface. Dew may form on the ground, on blades of grass, on leaves of shrubs, on auto tops, on garage roofs, or in fact on anything that has a temperature which is lower than the dew point of the air that touches it. The objects just mentioned become cooler than the air at night because they consist of materials that radiate heat more rapidly than air does. When dew forms on a surface, it means that the air has reached its dew point only where it is touching that surface. The clearer the night the greater the cooling by radiation and the heavier the dew.

If the temperature at condensation is below 32° F or 0° C, feathery white crystals of *frost* will form, since the water vapor goes directly into the solid form. *Frost, then, is not frozen dew,* although there is such a thing as frozen dew. If condensation first occurs at temperatures above freezing, and the temperature continues to drop below 32° F, the drops of dew will freeze into clear ice pellets. When temperatures near the ground drop below 28° F, plant cell liquids may freeze, bursting the cell walls and killing

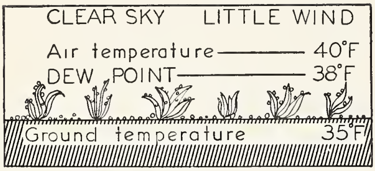


Fig. 6–1. The formation of dew by contact cooling. When the temperature of the ground falls below the dew point but not below 32° F, dew is formed.

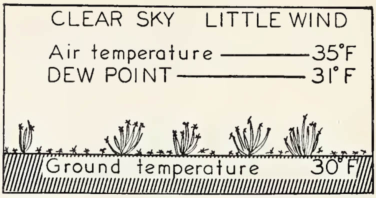


Fig. 6–2. Frost forms by contact cooling when the dew point is below 32° F. The water vapor of the air condenses in the solid form of ice crystals.

the plants. Such occurrences, called *killing frosts*, have nothing to do with atmospheric moisture.

Anything that tends to keep the lower air from cooling below its dew point diminishes the likelihood of dew, while anything that tends to keep the air from falling below the freezing point helps to prevent frost. Cloudy skies act like blankets which prevent loss of heat by radiation. Winds stir the air and keep it from too long contact with cold surfaces. Dew and frost are therefore less likely to form on cloudy or windy nights. Fruit growers, fearing early-spring or late-fall killing frosts, may use smudge pots to produce smoky flames to protect tender young blossoms or ripe fruits. The flame warms the air directly, while its smoke acts as a blanket which, like clouds, prevents excessive loss of heat by radiation. On a much larger scale the same idea was used during World War II to "burn away" fogs at operational airfields. This device is known as FIDO, a contraction for "Fog, intensive dispersal of."

3. Fogs and their formation. As explained above, the formation of dew means that the air has been cooled below its dew point only where it is touching surfaces that are cold enough. But it often happens that the cooling of the air extends through a considerable thickness of the bottom air, so that anywhere from a few feet to a few hundred feet of the lower air are cooled below the dew point, and water vapor condenses throughout this entire air layer. When this happens, tiny droplets of water or crystals of ice, depending on the temperature of condensation, fill the air and form a *fog*. Each droplet is about 0.001 inch in diameter and centered about a dust particle as a condensation nucleus. The droplets are heavier than air, but they are so small and they fall so slowly that the lightest air movement is sufficient to keep them suspended.

Radiation fogs, or *ground fogs*, form under conditions very similar to those which favor the formation of dew or frost. Again the nighttime sky is clear and the ground loses heat rapidly by

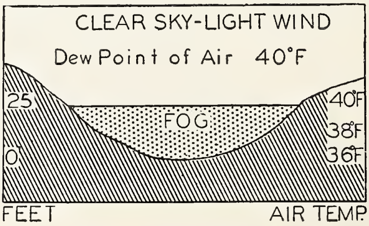


Fig. 6–3. Radiation fog forms at night when the lower air is cooled below its dew point. Since the lower air is cooler than the upper air, a temperature inversion exists.

radiation. But instead of a dead calm, there are often light winds which mix the cold bottom air with the air a short distance above the surface. As a result, a thicker layer of air is cooled below dew point, and fog forms in this layer. Without this mixing, only dew or frost would form in the thin layer next to the ground. Radiation fogs are especially common in humid valleys near rivers or lakes and are most frequent in the fall of the year. Following the day's temperature curve, these fogs form in the cool of night, are thickest in the early morning, and are "burnt away" by the morning rays of the sun. Since the bottom air in this fog is colder than the air above it, a radiation fog is always associated with a temperature inversion (see Chapter 2, Topic 15).

Advection fogs are fogs that result from the horizontal movement of warm moist air over a cool surface. In northern United States or southern Canada, advection fogs may form in winter when warm moist southerly winds blow over snow-covered ground or over ice-covered lakes or seacoasts. They may also form, as in the famous fogs of Newfoundland, when warm moist Gulf Stream air blows over the cold Labrador Current, or over great icebergs. Summer fogs in coastal California result when warm ocean air strikes cold coastal waters. Winter fogs along the Gulf coast occur when cold Mississippi River waters flowing from the north chill the warm Gulf air at its mouth.

Upslope fogs often form on the eastern side of the Rocky Mountains as warm moist winds from a high-pressure area blow westward over the mountains and are cooled by expansion. *Steam fogs* are important only in Arctic regions, where they are known as "arctic sea smoke." However, such fogs are often observed in southern Canada on a small scale, and their explanation is of considerable interest. They result when very cold air blows over much warmer water. The warm water evaporates rapidly, and as the water vapor meets the much colder air above it, it condenses into fog. This accounts for the "steaming" of city sewers, or of a pail of cold water, or of any liquid water source exposed to the air during extremely low temperatures.

4. The origin of clouds. A cloud brought down to the ground would look exactly like a fog. Conversely, a fog raised above the surface would appear to be a cloud. An observer in a valley may see what he calls a cloud resting on a mountain peak. To the climber at the peak, the same cloud represents a fog. Clouds, like fogs, consist of tiny water droplets or ice crystals suspended in the air. Fogs touch the ground; clouds do not.

Clouds are produced when air above the surface is cooled below its dew point. The cooling may come about through any one of the processes listed in Topic 1 or through combinations of these processes. But since clouds form above the earth's surface, rising air is usually involved in their formation. The shapes of clouds are determined by their manner of formation. If the movement of the cooling air is largely horizontal, the clouds will form in layers and are said to be *stratiform*. If the air movement is

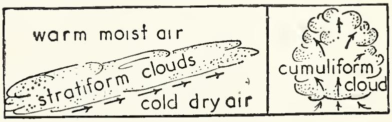


Fig. 6–4. Cloud shapes are related to the direction of air movement. Air movements that are largely horizontal produce stratiform clouds. Vertical movements produce cumuliform clouds.

largely vertical, the clouds will grow upward in great billowy mounds described as *cumuliform* (see Figure 6–4).

At temperatures above freezing, clouds are composed of water droplets. When the temperature is below freezing, they consist of snow or ice crystals. Even in summer very high clouds may consist of snow or ice. Cloud shapes change constantly as some portions of the clouds evaporate while new portions are formed. In one place a cloud may gradually disappear, while a short distance away a new one develops out of a clear sky.

How light or dark a cloud appears to be depends largely on its thickness and its position with respect to the sun. Clouds opposite the sun reflect sunlight and look white. In line with the sun, they intercept its light, so thin clouds look white and thick clouds look gray or black, often with a "silver lining."

5. Classification of clouds. The Canadian Meteorological Service classifies clouds according to a system adopted by the International Meteorological Organization. Clouds are classified according to their form and appearance, but cloud forms are always found to be related to their heights above the surface. In this classification, the average heights given are for temperate or middle latitudes. They are not heights above sea level, but rather heights measured from the surface above which they occur. In equatorial regions cloud heights are greater; in polar regions they are less.

6. Cloud names and their meanings. An examination of the ten cloud names listed in the international classification shows three simple names—cirrus, stratus, and cumulus—and seven compound names. The three simple names represent the three basic cloud types, of which all the others may be regarded as combinations or variations. *Cirrus* (meaning "curl") clouds are thin, feathery, or tufted, and are so high that they are always composed of tiny ice crystals. All of the "High" family of clouds are of the cirrus type. *Stratus* (meaning "spread") clouds are low uniform sheets

Family	Height	Name and Abbreviation
A High Clouds	Top: 40,000′ Base: 20,000′	Cirrus Ci Cirrostratus Cs Cirrocumulus Cc
B Middle Clouds	Top: 20,000′ Base: 6,500′	Altostratus As Altocumulus Ac
C Low Clouds	Top: 6,500′ Base: Close to surface	Stratocumulus Sc Nimbostratus Ns Stratus St
D Clouds of Vertical Development	Top: Height of Cirrus Base: 1600′	Cumulus Cu Cumulonimbus Cb

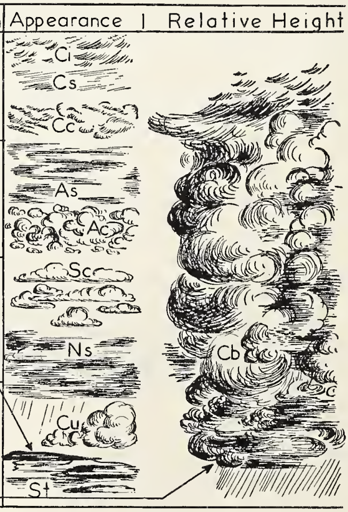
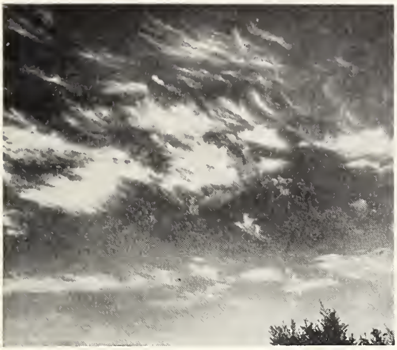
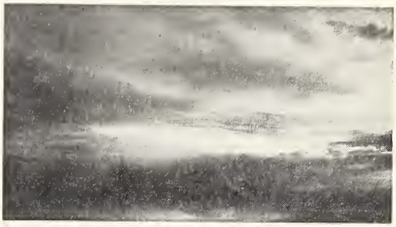


Fig. 6–5. Classification of clouds according to the international system.



F. Ellerman, U.S. Weather Bureau

Fig. 6–6. (a). Cirrus clouds.

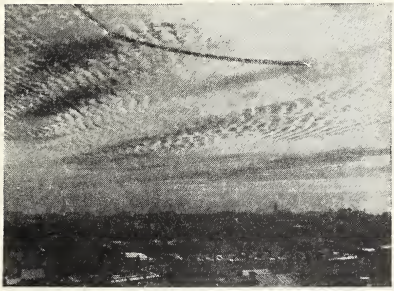


A. J. Henry, U.S. Weather Bureau

Fig. 6–6 (*d*). Altostratus clouds.

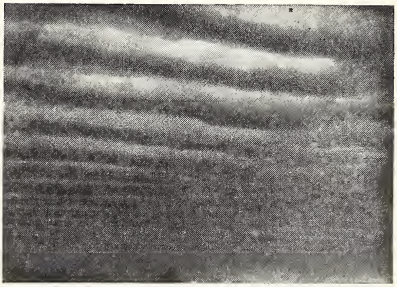
G. A. Clarke, U.S. Weather Bureau

Fig. 6–6 (*b*). Cirrostratus clouds showing halo.



A. J. Henry, U.S. Weather Bureau

Fig. 6–6 (c). Altocumulus clouds.



W. S. Davis, U.S. Weather Bureau

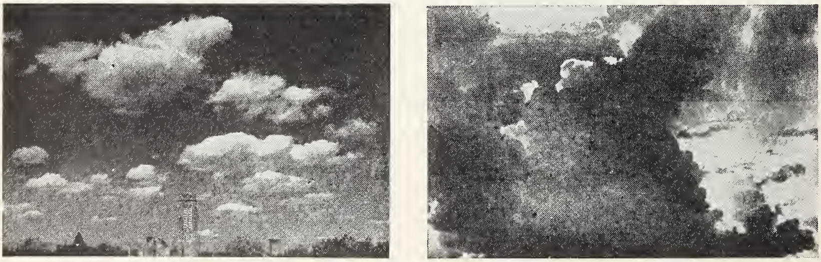
Fig. 6–6 (e). Stratocumulus clouds.

or layers of cloud. Fogs are often defined as stratus clouds on the ground, while stratus clouds may be spoken of as high fogs. *Cumulus* (meaning "heap") clouds are formed by vertically rising air currents, and are piled high in thick fleecy masses (see Figure 6–5).

When two of these words are combined, it implies that the cloud so named has some characteristics of each main type. For example, *cirrostratus* clouds are high, thin, feathery sheets or "veils" of ice-crystal clouds. They sometimes produce halos, or "rings," around the moon and sun, and may indicate the approach of rain. *Stratocumulus* clouds are layers composed of globular masses or rolls, often covering the whole sky, especially in winter. *Cirrocumulus* clouds are patches of small globular ice-crystal clouds heaped up from cirrus or cirrostratus clouds.

The prefix *alto*, meaning "high," and the word *nimbus*, meaning "raincloud," are also used in forming compound cloud names. *Altocumulus* look like higher, thinner stratocumulus clouds in smaller masses. *Altostratus* clouds look like thick cirrostratus at lower altitudes, gray or bluish in color, through which the sun or moon shows vaguely as through ground glass, or not at all. *Nimbostratus* clouds are dark gray low layers, uniformly dense and threatening, from which steady rain or snow may develop. The prefix *fracto* which means "broken," is often used to describe clouds that have been torn apart by strong winds. An example is *fracto-stratus*, often seen below rain clouds.

7. Cumulus and cumulonimbus. When convection takes place to a height sufficient to reach the dew point of the vertically rising air, *cumulus* clouds are formed. These clouds often appear in the late morning or early afternoon of bright sunny days, the products of unequal heating of the surface, and are regarded as fair-weather clouds. Flat-based with dome-shaped tops, they always indicate rising air currents. The flat base represents the level at which the rising air has cooled to its dew point, for it is there that the water vapor begins its condensation. The billowy tops indicate the height which the rising air currents reach before condensation dies out. The stronger the convection, the thicker the cloud. Ordinarily, cumulus clouds are most numerous in the afternoon and disappear toward evening. On hot summer days when humidity is high, or in other circumstances favoring strong convection, cumulus clouds may grow very rapidly to mountainous heights, forming cumulonimbus, or thunderhead, clouds. *Cumulonimbus* clouds are characterized



H. T. Floreen, U.S. Weather Bureau

Courtesy U.S. Weather Bureau (Photo by U.S. Navy)

Fig. 6–7. (a) Cumulus clouds of fine weather, with flat bases and rounded tops; (b) cumulonimbus cloud or thunderstorm cloud.

by heavy showers of rain, snow, or hail, often accompanied by thunder and lightning (see Figures 6–5 and 6–7).

8. Condensation level. When the temperature and dew point of the air at the ground are known, the height at which cumulus clouds will begin to form in rising air can be calculated. The rate of cooling by expansion is 5½° F per 1000 feet rise (see Chapter 2, Topic 16). As air rises, however, its dew point is also dropping at the rate of 1° F per 1000 feet, because the expanding air contains less water vapor per cubic foot than it had at the surface. The net result is that the dew point is approached at the rate of 4½° F for each 1000 feet rise. As an illustration, at the surface, air temperature is 69° F, dew point is 60° F; the difference between them is 9° F. Nine is divided by 4½, giving 2 as the number of thousands of feet rise necessary for the beginning of condensation. This level is known as the *lifting condensation level;* it is of considerable importance in weather forecasting.

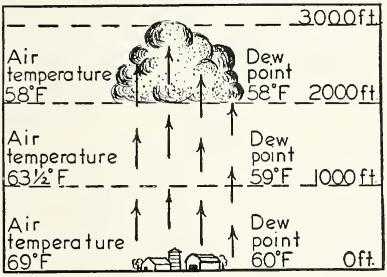


Fig. 6–8. The condensation level in a cumulus cloud can be determined when the dew point is known. Rising air cools at the rate of 5½° F per 1000 feet.

$$\text{L. C. L.} = \frac{T_A - T_D}{4.5} \times 1000 \text{ feet}$$

(L. C. L. is the lifting condensation level; T_A is the surface air temperature; T_D is the surface dew point.)

9. Moist-adiabatic lapse rate. In Figure 6–8 the air temperature at the base of the cloud is calculated by using the dry-adiabatic lapse rate of 5½ degrees Fahrenheit per 1000 feet. Above the cloud base, however, air does not cool at the same rate because, as water vapor condenses, heat is released. See Chapter 5, Topic 7. The amount of heat released depends on the amount of water vapor condensed. An average situation is one in which the heating effect of condensation in a 1000 foot rise is about 2½ degrees Fahrenheit. This reduces the net cooling by expansion in the same distance from 5½ degrees to about 3 degrees. To illustrate, at 3000 feet in the air in Figure 6–8 would be approximately 3 degrees (not 5½ degrees) cooler than at 2000 feet. Thus its temperature would drop to 55° F rather than to 52½° F. This cooling rate in rising saturated air is called the *moist-adiabatic lapse rate.* Unlike the dry-adiabatic lapse rate, it is not a fixed quantity.

10. Clouds on the weather map. The station models on Dominion Public Weather Office charts give very detailed information about the clouds in the sky. The total amount of sky covered by clouds is estimated by the weather observer, reported in tenths, and shown by shading in the station circle. The Weather Office uses as many as ten symbols to show *sky coverage,* as it is called. Newspaper weather maps go into less detail, showing only three different symbols (Figure 6–9).

By means of codes and symbols explained on the back of the weather map, the station model also shows the *type of cloud*—low, middle and high—that is present at each level, the *height of*

SYMBOLS SHOWING PERCENTAGE OF CLOUDINESS

Tenth of Sky Covered	0	1	2	3	4	5	6	7	8	9	10
Canadian Weather Maps	○	⦶	◔	◔	◔	◑	◑	◕	◕	⦶	●
Newspaper Maps	○				◑				●		

Fig. 6–9. Symbols used to show how cloudy the sky is.

the cloud base, and the *amount of sky covered by the low clouds.* Arrows are used to show the directions in which the clouds are moving.

11. A ceiling of clouds. An aviator flying over a thick layer of clouds cannot see the ground beneath him. Obviously, it is vitally important for him to know how close the base of the clouds is to the ground. The Weather Office provides this information in what is called the *ceiling.* The clouds are regarded as forming a "ceiling" over the ground only if there are enough clouds within 10,000 feet of the surface to cover more than half of the sky. Thus the *ceiling is the lowest level* (below 10,000 feet above the ground) *at which just half of the sky is covered by clouds.* When less than half the sky at this level is covered by clouds, the ceiling is said to be *unlimited.* When dense fog or heavy precipitation make it impossible to see the cloud base, the ceiling is reported as *zero.*

12. Finding the ceiling. There are many methods of finding the ceiling. The ceiling can be estimated by an experienced observer, or it can be measured with the aid of pilot balloons, ceiling balloons, ceiling searchlights, or radar equipment.

As explained before (Chapter 4, Topic 6), *pilot balloons* that rise at constant speeds of about 600 feet per minute are used in measuring upper winds. If the time taken by a pilot balloon to reach the cloud base is noted, the ceiling can easily be calculated. A time of two minutes, for example, would mean a ceiling of 1200 feet. *Ceiling balloons* are smaller than pilot balloons —about 1½ feet in diameter when inflated—and they rise more slowly. Being less expensive, they are used if the ceiling is to be found at times when pilot-balloon observations are not being made. Like pilot balloons, ceiling balloons can be followed at night by hanging small lanterns from them.

A *ceiling searchlight* is simply a searchlight that shines a strong beam of light almost straight up at the clouds. An observer standing at a known distance from the light—usually 1000 feet away —measures the angle above the ground at which he sees the spot of light on the cloud base. The higher the cloud base, the larger the angle. The ceiling can then be calculated by trigonometry or found in a table. Special ceiling searchlights have been developed for daytime use, photoelectric receivers being em-

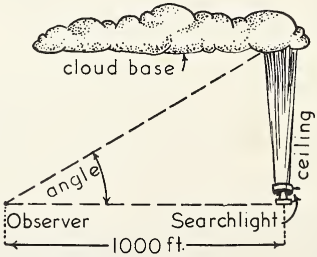


Fig. 6–10. Finding the ceiling with the aid of a ceiling searchlight.

ployed to detect the "invisible" spot of light on the cloud base.

A still more recent development is the use of *radar,* which depends on the fact that radar waves, like light, are reflected back to the earth by thick clouds. The reflected waves are picked up by a receiver which shows how far away the clouds are.

13. Visibility. *Visibility* is the greatest horizontal distance at which landmarks of fair size, such as a house, water tower, or mountain peak, can be recognized. On Canadian weather maps the visibility is stated in miles, directly between the dew point and the temperature at the left side of the station model. In Figure 6–11, the visibility is 1½ miles. When the visibility is more than 10 miles, it is "unlimited," and is not shown on the map. In fog, heavy rain, or snow, the visibility may be *zero.*

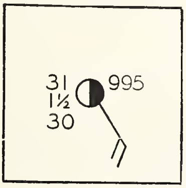


Fig. 6–11. Station model showing temperature, pressure, dew point, wind direction, wind force, sky cover, and visibility.

14. Cloud in a bottle. The formation of a cloud through cooling by expansion can be shown in an interesting demonstration. A small quantity of a volatile (fast-evaporating) liquid, such as alcohol, chloroform, or carbon tetrachloride, is put into a flask fitted with a two-hole rubber stopper. A pinch-clamp closes one opening. Through the other opening air is carefully pumped in. The air, warmed by compression, evaporates a large quantity of liquid. When the pinch-clamp is opened, sudden expansion of the air in the flask produces adiabatic cooling. The air is cooled below its dew point, vapor condenses, and a cloud is formed in the flask. A quick stroke of the pump and the cloud disappears, partly because of evaporation again into the warm compressed air and partly because it is blown away as by a wind.

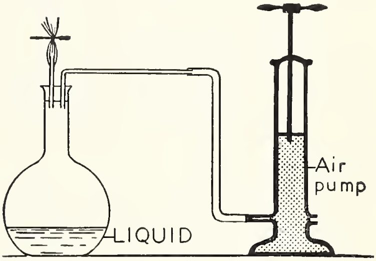


Fig. 6–12. Apparatus for demonstrating the formation of a cloud.

The cloud that is formed in this experiment may be greatly improved, and the effect of "condensation nuclei" shown by putting some match or cigarette smoke into the air of the flask immediately before doing the experiment. (If alcohol or any other combustible liquid is used, flames must be kept away from the flask.) The tiny quantity of smoke, invisible in the flask, nevertheless contains thousands of minute particles on which water vapor may condense, and a heavier cloud results. The cloud can best be seen under a spotlight in a darkened room.

15. Smog. In recent years large cities such as New York and London, as well as small industrial cities and communities, have been plagued by a combination of smoke and fog to which the name *smog* has been given. Smog is most likely to form during times when little or no convection is taking place in the atmosphere over these areas. Without rising air currents to carry them away, the smoke and chemical fumes from home and factory chimneys combine with fog particles in the air to form a dense cloud that is often harmful to health. Many deaths have been attributed to the poisonous industrial gases, normally escaping from chimneys into the upper atmosphere, that smog has kept close to the earth's surface. In England such deadly smogs are known as "killer fogs."

Smog may linger for many days, to be dispersed only when the weather changes. Smogs, like fogs, are often connected with or caused by the presence in the atmosphere of a temperature inversion (see Topic 3). The cool air at the earth's surface not only brings about condensation but also prevents convection.

HAVE YOU LEARNED THESE?

Meanings of: cumuliform; stratiform; cirrus; stratus; cumulus cumulonimbus; ceiling, visibility; cloud families

Diagrams of: sky cover

Explanations of: how condensation occurs; how air cooling occurs; formation of dew; formation of frost; formation of fogs; types of fogs; origin of clouds; what clouds are; cloud families; cloud names; condensation level; moist-adiabatic lapse rate; finding the ceiling

Relations between: cloud height and composition; cloud form and direction of air movement; clouds and fogs

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is meant by condensation? (*b*) What must always happen if water vapor is to condense? (*c*) List the 4 ways of cooling that may cause condensation.

2. (*a*) Explain and describe the formation of dew. (*b*) What is frozen dew? How can it form? (*c*) What condition causes formation of frost instead of dew? (*d*) What is a killing frost? (*e*) What natural conditions reduce the probability of frosts? (*f*) How does the smudge pot help to prevent frost?

3. (*a*) Explain how a fog forms. Describe its composition. (*b*) Describe the origin and occurrence of radiation fogs. (*c*) Define advection fogs. Briefly explain one or two illustrations of such fogs. (*d*) Explain what steam fogs are.

4. (*a*) Compare clouds with fogs. (*b*) How do clouds form? What connection is there between cloud shapes and manner of formation? (*c*) What are clouds made of? Why do their shapes constantly change? (*d*) What makes a cloud light or dark?

5. (*a*) Explain the basis for the international classification of clouds. (*b*) Give the names and height ranges of the four cloud families. From where are their heights measured?

6. (*a*) Name and describe the three basic cloud types. (*b*) Define alto, nimbus, and fracto. (*c*) Give two or three illustrations that show the meaning of compound cloud names. (*d*) What special phenomena help to identify cirrostratus clouds? altostratus clouds? (*e*) Which clouds are always made of ice crystals?

7. (*a*) Explain how cumulus clouds are formed. (*b*) Why do they appear in fair weather? (*c*) What level is shown by the flat base of a cumulus cloud? (*d*) Describe the origin and characteristics of a cumulonimbus cloud.

8. If the temperature and dew point of air at the ground are known, explain how the condensation level can be determined.

9. (*a*) What is the moist-adiabatic lapse rate? (*b*) Why is it less than the dry-adiabatic lapse rate? (*c*) Why is it variable?

10. (*a*) Copy and describe the symbols used on both Meteorological Office and newspaper weather maps to show how cloudy the sky is. (*b*) Besides cloudiness, what other cloud data are shown on the station model?

11. Define ceiling. Why is it important?

12. Describe three different ways of finding the ceiling.

13. (*a*) What is visibility? How is it shown on Canadian Weather Office maps? (*b*) Read all the weather data in Figure 6–11.

14. (*a*) Which method of cooling air below its dew point is used in the cloud experiment? (*b*) What are condensation nuclei?

15. (*a*) Under what conditions does smog form? (*b*) Why is smog dangerous to health?

GENERAL QUESTIONS

1. How may spraying an orchard with water help to prevent frost formation?

2. Why are dew and frost less likely to form under trees than in the open?

3. Why may dew not form on the ground under a tent?

4. Besides atmospheric moisture, what other possible sources are there for the water that forms dew on leaves or grass?

5. Why are cloud heights greater at the Equator than at the Poles?

6. In distance and altitude contests, free (not towed) glider pilots always try to go beneath cumulus clouds. Why?

7. At what height will condensation occur in rising air that starts out with a temperature of 60° F and a dew point of 42° F? What will the temperature be at the base of the cloud formed?

8. If a cumulonimbus cloud is 10,000 feet tall and the temperature at the base is 40° F, what is the temperature at its top? (Assume an average moist-adiabatic lapse rate of 3 degrees Fahrenheit per 1000 feet.)

9. How can the amount of cooling that takes place in the "cloud flask" of Topic 11 be measured or calculated?

10. Why are volatile liquids rather than water suggested for the cloud experiment?

11. Why are fall nights more favorable for ground-fog formation than spring nights?

12. Why are light winds more favorable for ground-fog formation than either strong winds or calms?

STUDENT ACTIVITIES

1. Keeping weather records to show the relation between dew formation, the state of the sky, and the wind velocity
2. Observing and naming cloud types daily
3. Photographing clouds
4. Collecting photographs of clouds from newspapers and magazines
5. Estimating ceiling and visibility
6. Measuring cloud heights by trigonometry
7. Observing the direction of cloud movement and upper winds

SUPPLEMENTARY TOPICS

1. Clouds on the Weather Map
2. Clouds in the Tropics
3. Clouds and Seasons
4. Cloud Types, Symbols, and Codes of the Canadian Weather Office
5. Destructive Frosts: Seasons, Dates, Regions
6. Smog
7. Fogs in London
8. Variations in the Moist-Adiabatic Lapse Rate
9. Ceiling on the Weather Map
10. Ceiling Measuring Methods
11. Hygroscopic Chemicals and Condensation Nuclei
12. Cloud Chambers

See list of suggestions for further reading at the end of Chapter 1.

Chapter 7

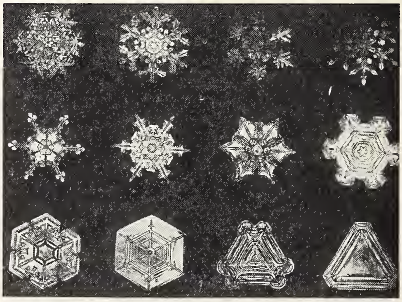
THE PRECIPITATION OF MOISTURE

1. Precipitation and relative humidity. According to the dictionary, precipitation is "the state of being thrown downward." In meteorology, precipitation is the throwing-down of moisture from the clouds to the surface of the earth. Clouds are condensation forms, but the rains that fall from them are precipitation forms.

Just when and why a cloud will precipitate its moisture is still not entirely understood by meteorologists. But several things are obvious. Apparently the small droplets of water or crystals of snow or ice become larger and heavier until air movement no longer supports them. They may grow larger by continued condensation on them or by merging with other water or snow particles. This usually happens only in thick clouds. The drops of moisture do not evaporate completely as they fall through the air, or they would never reach the ground. Thus, often a cloud drops rain on the slopes of a mountain, while in the valley below there is no rain because the raindrops evaporate on their way down.

People may wonder why a Weather Office report gives the relative humidity as only 80 per cent or 90 per cent when it is raining heavily. The answer, of course, is that the base of the rain cloud is usually *several thousand feet above* the earth's surface, whereas the relative humidity which is reported is that of the air near the earth's surface at the observing station. Within the cloud itself the relative humidity is probably 100 per cent. When the relative humidity just above the ground is 100 per cent fogs are formed.

2. Forms of precipitation. Precipitation occurs in a variety of forms. *Drizzle* consists of extremely fine drops very close together falling very slowly. *Raindrops* are larger and farther apart than drizzle, varying in diameter up to 0.1 inch. *Snow* consists of branched hexagonal (six-sided) crystals or stars except at very low temperatures, when very fine



Courtesy U.S. Weather Bureau (by *W. A. Bentley*)

Fig. 7–1. Snow crystals photographed under the microscope.

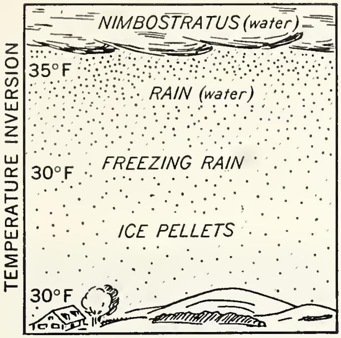


Fig. 7–2. Ice pellets are formed when raindrops freeze as they fall through a layer of below freezing air. Ice pellets can form only if a temperature inversion exists.

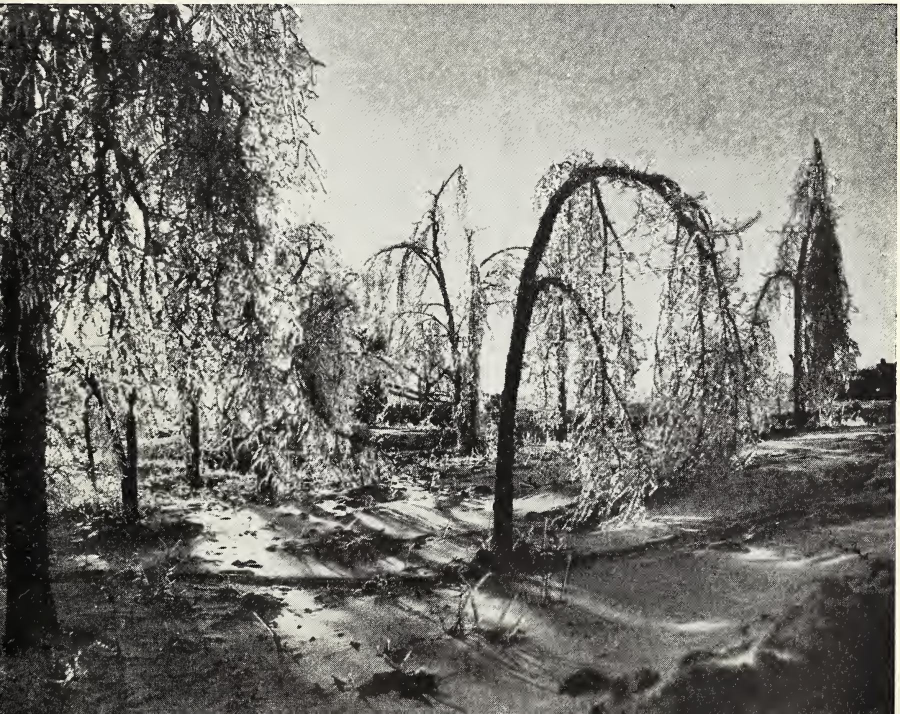
ice needles are formed. Snowflakes falling into warm air melt together to form large clots of wet, sticky snow, or they may melt completely and reach the surface as rain.

In winter, temperature inversions may cause below-freezing layers of air at or near the ground while rain clouds lie above them. Raindrops falling through the freezing layers become pellets of clear ice. This frozen rain is called *ice pellets* (Figure 7–2).

Frequently during the winter in central and eastern Canada, rain freezes only after it reaches the surface of the earth, forming *sheet ice* or *glaze* on everything it touches. If this condition continues for some time, it is called an *ice storm*. Ice storms create fantastically beautiful forest spectacles, but the damage they do often costs millions of dollars. The rapidly accumulating ice layers soon form insupportable weights which cause tremendous numbers of branches of trees and shrubs to collapse. Electric transmission lines may be smashed, and highway communications paralyzed.

Fig. 7–3. An ice storm in New York State early in January, 1943.

Courtesy U.S. Weather Bureau



Sleet is a winter phenomenon. *Hail,* on the other hand, is formed almost exclusively in summer thunderstorms. Hailstones may be as small as peas or as large as tennis balls, but, whether they are large or small, their structure is the same. A hailstone is formed somewhat like an onion; it has an icy center surrounded by alternating layers of snow and ice. The greater the number of layers the larger the hailstone. Apparently the violent updrafts of the cumulonimbus thundercloud, instead of allowing even large raindrops to fall, will carry these drops miles high into the upper reaches of the cloud where the temperatures are far below freezing. The raindrops turn to ice as soon as they enter the freezing levels. At this stage they are like sleet going the wrong way. Continuing upward, they reach the snow levels of the cloud, where they become snow-coated and heavier. They fall back into the lower water levels, acquire another coating of water, and may again be caught in strong updrafts which repeat the previous process.

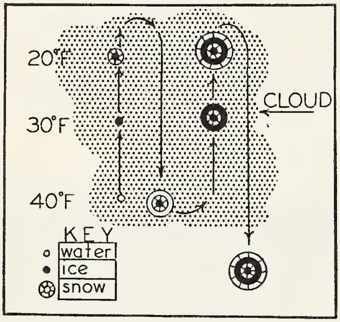
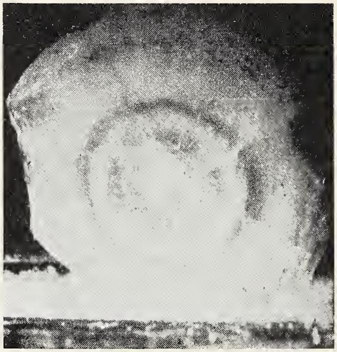


Fig. 7–4. The growth of a hailstone in a cumulonimbus cloud.

The more violent the storm, the more ups and downs for the hailstones and the larger they grow, until they become too heavy for the updrafts to support. The size of a hailstone is a measure of the strength of the whirling air currents. The worst hailstorms in the world occur on the Great Plains of North America. In one of these storms the largest single hailstone on record fell at Potter, Nebraska, on July 6, 1928. It was about the size of an indoor baseball.

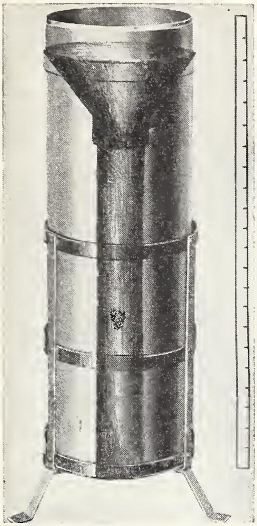


Courtesy U.S. Weather Bureau

Fig. 7–5. Layers of ice and snow beautifully shown in a hailstone that fell at Iowa City, Iowa on June 18, 1940.

3. Measuring precipitation. Rainfall is measured in inches and hundredths of an inch by means of an instrument called a rain gauge. The measurement is supposed to represent the thickness of the water layer that the rain would leave on a perfectly level surface if no rain were lost. Any cylindrical container placed in the open can serve as a rain gauge. In the standard observatory rain gauge a brass funnel directs the rain into a narrow cylindrical tube. The mouth of the funnel has ten times the area of the mouth of the tube. The tube therefore receives ten times as much rain as it would receive alone. This larger amount is easier to read, but of course it must be divided by ten to give the actual rainfall. A marked stick is dipped into the tube to get the reading. Other forms of rain gauge automatically record both the time and the amount of the rainfall.

Snowfall, like rainfall, is measured in inches and tenths of an inch. A simple measuring stick is used. The measurement is usually taken in as open and average a location as is possible. The water or rain equivalent of the snowfall is determined by melting a definite depth of the snow. Dry snows pile up much higher than equal weights of wet snow. On the average, ten inches of snow equal one inch of rain, but this may vary from as little as five inches of snow to as much as thirty inches.



Courtesy Friez Instrument Division

Fig. 7–6. Standard rain or snow gauge, showing interior parts and measuring stick.

4. Precipitation on the weather map. Shading is used on Weather Office maps to show large areas in which *precipitation is occurring.* Total precipitation for the last six hours is given in hundredths of an inch, below and to the right of the station circle, as shown in Figure 7–7. In newspaper weather maps, shading usually indicates areas which *have had precipitation* in the past six hours, but total precipitation is shown, as on the Weather Office maps, near the station circle.

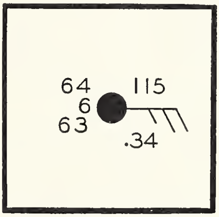


Fig. 7–7. Station model showing temperature, pressure, dew point, wind direction, wind force, sky cover, visibility, and amount of precipitation.

The *form* of precipitation is shown beneath the station circle by symbols explained on back of the weather map in a detailed table called "Present Weather." This table contains a hundred symbols, but they include various arrangements and combinations of just a few basic symbols that show drizzle, rain, snow, sleet, hail, thunderstorms,

NAME	*drizzle*	*rain*	*shower*	*snow*	*ice pellets*	*fog*	*hail*	*thunderstorm*
C.M.S. Symbol	,	•	▽	✱	◬	≡	△	☈
Newspaper Maps		Ⓡ		Ⓢ		Ⓕ		

Fig. 7–8. Symbols showing forms of precipitation on Weather Office and newspaper weather maps.

showers, and fog. The various arrangements merely show how hard or how steady the precipitation is. The basic symbols are shown in Figure 7–8. The simpler but less detailed symbols used on newspaper weather maps are also shown.

5. Where does it rain? Precipitation —rain, sleet, hail, or snow—can and does occur in every part of the world. But in some locations, such as parts of the desert of Peru, it does not rain for years at a time; in other places, as in the Amazon jungles, it may rain almost every day. Parts of Death Valley, California, average about one inch of rain a year, whereas Cherrapunji in India averages 457 inches a year. What accounts for such differences?

In general, condensation that is vigorous enough to lead to precipitation takes place only in rising currents, where air in large quantities is being cooled below its dew point by expansion. Wherever air rises high enough and in large enough quantities, there precipitation will occur. The warmer the air, the more moisture it may contain, although that will also depend upon where it comes from. Within limits, the higher the air rises, the more moisture it can drop. It follows, therefore, that *the rainy regions of the earth will be the regions where air often rises in large quantities.* The more often this happens, the more frequently will it rain. Such regions are the following: (1) the entire *doldrums belt* of warm, humid, convectionally rising air that reaches up to the stratosphere to form gigantic cumulonimbus clouds and almost daily thunderstorms; included in here are the densely forested jungles of the Amazon, the Congo, and the East Indies; (2) the *windward sides of mountain ranges,* where prevailing winds are forced to climb to great heights; examples are the rainy western slopes of the Cascade Mountains in northwestern United States, and the rainy eastern slopes of the mountains of Central America in the trade-wind belt; (3) *storm areas* of all kinds, such as hurricanes, typhoons, cyclones, fronts, thunderstorms, and tornadoes, for in all of these there are great masses of moist rising air. Storm areas will be described fully in Chapters 9 and 10.

Places over which the doldrums shift have almost daily rains while the doldrums are over them. Places windward of mountains have heavy rains whenever the winds blow from a moist source. Other locations have rain only when they have storms of one kind or another. "Rain" here means any form of precipitation. Compare the rainiest areas of the world-precipitation map, Figure 7–10, with the "rainy region" list given in this topic.

6. Where does it not rain? The answer to this question is almost the exact

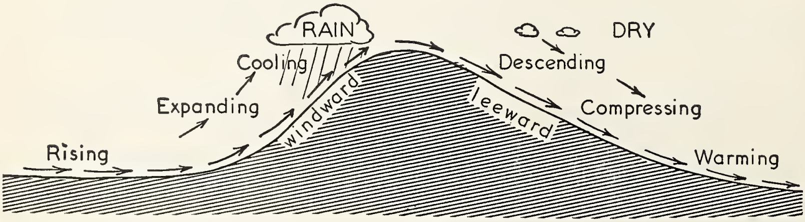


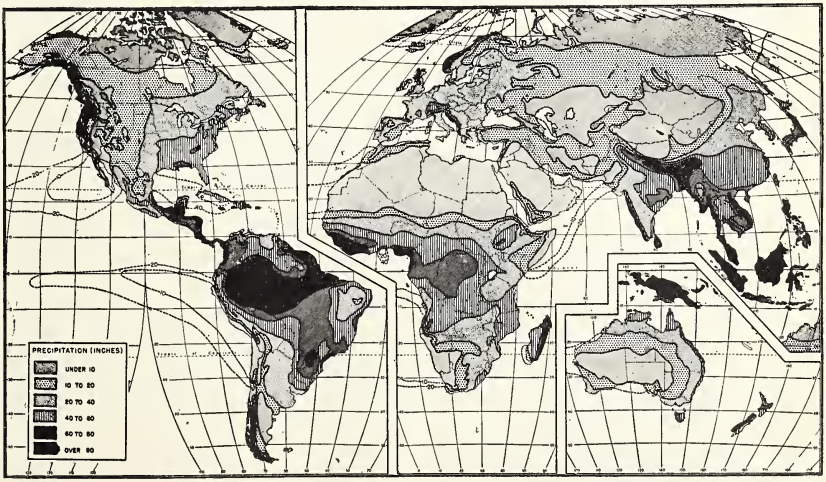
Fig. 7–9. Precipitation is usually heavy on the windward side of a mountain and very light on the leeward side.

opposite of the answer to "Where does it rain?" *In regions of descending air, the air is being warmed by compression, and no precipitation can occur.* The air may become so warm and dry that it causes excessive evaporation and creates desert conditions. Three regions of descending air, in which rains rarely occur, include: (1) the *two horse-latitude belts*; (2) the *leeward sides of mountains*; (3) the central portions of middle-latitude *highs or anticyclones* (which will be fully described in Chapter 10).

A fourth and extremely important region of "no rain" has a somewhat different explanation. The trade winds of both hemispheres blow toward the Equator into warmer latitudes, and so they become warmer even though they do not descend. As they move they pick up moisture, which they drop only where they are forced to rise over mountains. Hot and dry, they are largely responsible for such great desert areas as the Sahara Desert of Africa and the Atacama Desert of Peru.

Locate the arid regions of the world on the world-precipitation map, Figure 7–10, and see which of the reasons given above accounts for each region's lack of rain.

7. Precipitation in the prevailing westerlies. In the belts of prevailing westerlies and polar easterlies, storms are far more frequent than in the trades. As a result, even the leeward sides of high mountains are never as dry as similar trade-wind areas. While the windward sides of high mountains are rainy areas, just as in the trades, fairly heavy rains may also occur in any region which is visited by frequent storms, especially if it is fairly close to the ocean. The heaviest annual rainfall in Canada falls on the leeward slopes of the Coast Range of British Columbia, dropped by the ascending prevailing westerlies. But appreciable amounts of rain also fall in the less mountainous parts of the country, with the total annual precipitation becoming larger and larger towards the east as the Atlantic is approached. This is



Courtesy U.S. Weather Bureau

Fig. 7–10. Average yearly precipitation of the continents.

because of both the larger number of storms in these regions and the higher humidity of the winds blowing into the storms from the adjacent ocean.

8. Rainmaking. In recent years numerous attempts have been made to produce rain artificially. Probably the largest project of this kind was the one conducted by the Board of Water Supply of New York City during the spring of 1950, in an effort to overcome the effects of a near-drought in its watershed during 1949. In one method of "cloud-seeding," pellets of *dry ice* (solid carbon dioxide) are dropped from airplanes into "promising" clouds—usually cumulus clouds in which convection appears to be increasing. The extremely cold pellets cause the formation of ice crystals which are supposed to be helpful in making a cloud precipitate its moisture. In another method, a special smoke generator on the ground sends billions of microscopic particles of *silver iodide* into the cloud to act as condensation nuclei around which additional water vapor will condense as water or ice, thereby precipitating rain.

Some of the experiments seem to have been successful; others have not. In all cases, the experiments are done with clouds that already exist and appear likely to produce rain. Cumulus clouds are often chosen with the idea that they will grow into cumulonimbus. When rain does come, it is almost impossible to prove that it would not have come anyway, or that the amount has been increased. It will probably require extensive statistical studies over a long period of years to prove the case for or against the rain-maker.

HAVE YOU LEARNED THESE?

Meanings of: sleet; rain gauge

Descriptions of: hailstones; rain gauge

Explanations of: formation of rain, sleet, hail, glaze, snow; rainy regions; dry regions; precipitation in the westerlies; rain-making

Relations between: rising air and precipitation; descending air and dryness; mountains and precipitation

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) In meteorology what is precipitation? (*b*) Why does a cloud precipitate its moisture? (*c*) How can the relative humidity be only 80 per cent when it is raining?

2. (*a*) Distinguish between drizzle and rain. (*b*) What is the structure of snowflakes? (*c*) What effect does warm air have on falling snow? (*d*) Explain how sleet is formed. (*e*) What is an ice storm? (*f*) Describe the structure and origin of a hailstone.

3. (*a*) What is a rain gauge? Describe one type. (*b*) How is snowfall measured?

4. (*a*) How is amount and place of precipitation shown on the weather map? (*b*) Read the weather data shown in Figure 7–7.

5. (*a*) When does condensation usually lead to precipitation? (*b*) Name the three kinds of regions in which rising air causes rain. Explain why the air rises in two of these regions. Name some places located in them. (*c*) Copy and learn the diagram showing the influence of mountains on precipitation.

6. (*a*) Why are regions of descending air dry? (*b*) Name three regions of descending air and explain why the air descends in two of them. (*c*) Why are the trade-wind belts so dry? (*d*) Under what conditions does it rain even in the trades?

7. (*a*) Why are deserts in the westerlies never as dry as in the trades? (*b*) What accounts for fairly heavy rainfall in eastern

Canada, even where there are no mountains? (*c*) Why does the annual precipitation in Canada east of the Rockies increase towards the Atlantic?

8. (*a*) What two substances are used to "make rain"? (*b*) Explain how each of these substances functions in "inducing" rain. (*c*) Why are the results inconclusive?

GENERAL QUESTIONS

1. Why are silver iodide generators on the ground used only with cumulus clouds?

2. How may dry-ice seeding tend to break up a cloud?

3. Why are winter hailstorms very rare?

4. The funnel used in a rain gauge has a cover in which there is only a small opening. How does this contribute to the accuracy of the measurement?

5. Why is there so much rain in Cherrapunji?

6. Why is there so little rain in Death Valley?

7. Why is average annual precipitation greater in Nova Scotia than in Manitoba?

8. Why is average annual precipitation greater in Mississippi than in New Brunswick?

9. Why is the leeward side of a mountain range said to lie in the "rain shadow" of the mountain?

STUDENT ACTIVITIES

1. Determining the relative humidity outdoors when precipitation is occurring, and during fogs
2. Measuring the size of raindrops, sleet, and hail
3. Making a rain gauge
4. Measuring rainfall and snowfall
5. Sketching or photographing snowflakes
6. Reading and learning weather codes on the weather map

SUPPLEMENTARY TOPICS

1. The Bergeron-Findeisen Theory (Why Precipitation Occurs in a Cloud)
2. Other Precipitation Forms (not mentioned in this chapter)
3. Snowflakes
4. Hailstorms; Updraft Velocities
5. Ice Storms
6. Rain Gauges
7. Precipitation Records: Canada and World
8. Precipitation (Present and Past Weather) Codes on the Weather Map
9. Rain-making Techniques and History

See list of suggestions for further reading at the end of Chapter 1.

Chapter 8

AIR MASSES AND THEIR WEATHER

1. What an air mass is. A glance at a weather map of southern Canada for almost any day of the year will rarely show the weather to be the same all over the country. Nor, however, is the weather different in every one of the country's thousands of cities, towns, and villages. As a rule, the whole country's weather can be summarized by describing not more than three or four different kinds of weather which prevail in different sections. On March 8, 1956 for example the weather across the country could be described as follows:

"The snow that fell earlier in the day in southern Ontario and southwestern Quebec has now moved into eastern Quebec and the Maritime Provinces. A belt of clear, cold weather extends from Newfoundland, north of the Gulf of St. Lawrence through northern Ontario to Saskatchewan. Cloudy, cool weather is being experienced in south British Columbia."

Careful examination of the weather map usually shows remarkable uniformity of temperature and humidity conditions over broad areas. On the other hand, temperature and humidity often change very abruptly from one broad area to the next. This uniformity of temperature and humidity within each great area exists not only in the air at the surface but also in the upper air to a height of several miles. Each of these tremendous masses of air, hundreds or even thousands of miles in diameter and several miles high, is known as an *air mass*. More specifically, *an air mass is a huge section of the troposphere in which temperature and humidity are fairly uniform at any given level.*

On the day referred to above, temperatures in the air mass covering the eastern Prairies, northern Ontario and northern Quebec included the following: southern Saskatchewan 10–12° F; Manitoba 5–10° F; northern Ontario 6–11° F; northern Quebec (except the extreme north) 3–10° F. From Regina to Knob Lake, Quebec is about 1500 miles. Skies were clear and humidity was low in all these areas. Here, then, was an area hundreds of thousands of square miles in extent, throughout which almost exactly the same weather prevailed.

2. Origin of an air mass. Where do air masses come from? How do they originate? Why are there several different kinds over North America at one time? Why are they different? These are questions that arise as soon as we recognize that there are air masses. Part of the answer can be supplied by looking at the weather maps for several days back to see when and where the uniform masses of air first appear. The maps must cover not only Canada and the United States but also parts of the Pacific and Atlantic oceans and the Gulf of Mexico. The maps show that usually great portions of the troposphere are "stagnant" or remain more or less stationary over one kind of surface, either continent or ocean, for many days or even weeks at a time. Contact with a uniformly warm or cold surface gives the air *uniform temperature.* Contact with a uniformly wet or dry surface gives the air *uniform humidity.* These characteristics make it an "air mass." When its time came to move, air that had been stagnant carried its uniform temperature and humidity with it.

3. Kinds of air masses. Basically, air masses owe their characteristics to the surfaces over which they originate. Those that originate in the tropics have temperatures that are higher than the normal for northern United States and Canada. They are called *tropical,* abbreviated *T.* Those that originate in polar regions have relatively low temperatures. They are called *polar,* abbreviated *P.* Besides being polar or tropical, the "source region" is either a continental area or an ocean (maritime) area. Air masses from continents are called *continental,* abbreviated *c,* while air masses from oceans are called *maritime,* abbreviated *m.* Continental air is relatively dry; maritime air is humid. Putting these together, there are four main kinds of air masses, as listed here.

Abbreviation	*Name*	*Characteristics*
cP	continental polar	dry, cold
mP	maritime polar	moist, cold
cT	continental tropical	dry, warm
mT	maritime tropical	moist, warm

These symbols are used on United States and Canadian maps to label air masses.

The term *Arctic,* A, is also used to designate an air mass from extremely cold, ice-covered arctic regions. *Equatorial, E,* refers to moist, hot doldrums air, which never affects North America. *Superior, S,* refers to air masses of the middle and upper troposphere. They are rarely found on the continent, but sometimes descend to the surface in southwestern United States. As a result of compression they are very warm and dry.

4. Source regions, movement, paths. The place where an air mass originates is called its *source region* or *source.* *cP* air masses develop over central and northern Canada; *mP* masses come from the North Atlantic and North Pacific oceans; *mT* masses come from the Gulf of Mexico, the Caribbean Sea, the middle Atlantic Ocean, and the Pacific Ocean south of California. *cT* air masses are not common but may originate in the southwestern desert region of the United States in summer. In general, the polar air masses move southward with the polar easterly winds; the tropical air masses move northward and eastward with the prevailing southwesterly winds. Figure 8–1 shows further

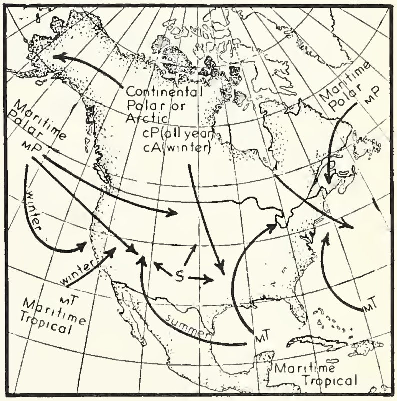


Fig. 8–1. Source regions and paths of air masses in the United States and Canada.

details of their seasonal occurrence and paths.

5. Weather in an air mass. Air masses are usually very extensive and may take many days to pass a given locality. During all this time the weather of the locality is determined largely by the original characteristics of the air mass. When a mass of cold dry *cP* air from northern Canada moves south in winter it is as if temporarily that portion of Canada and United States that is covered had an arctic climate. If it is winter, the *cP* air is usually felt as an icy, clear, cold wave that may last for many days and may extend as far south as Florida; in summer, *cP* air is much warmed by the time it reaches southern Canada but still brings cool weather. When *mP* air comes in from the oceans it brings cool humid weather in summer although it may be relatively warm in winter. *mT* air masses rarely enter Canada at the surface in winter; in summer they are responsible for the oppressively hot humid spells. Again, it is as if these regions were temporarily in the humid tropics from which the air masses originated. As one air mass after another passes over a locality, its weather may change from polar to tropical, from humid to dry, over and over again, accounting for the great variability of the weather in most of Canada.

6. Air masses undergo changes. An air mass that starts out from its source region in the Arctic and moves southward will obviously not stay cold indefinitely; it will warm up more and more the farther south it goes and the longer it is away from its source. Air masses that move from south to north become colder; those that move from ocean to continent become drier; those that move from land to water become more humid. The first days of a winter cold wave are the most frigid; then the cold wave slowly moderates and eventually the weather returns to "normal." In order to make accurate weather forecasts the meteorologist must take these modifications into account. He must know the following three things about an air mass: (1) its source region; (2) the path it has followed, and the surfaces over which it has passed; (3) how long it has been traveling. From this information he can deduce not only its present characteristics but also how the air mass is likely to develop in the next day or so, and what kind of weather it will carry.

7. A warm air mass. An air mass that is warmer (in its lower layers) than the surface over which it is passing is defined as a *warm air mass.* This term must not be confused with the term "tropical." A tropical (*T*) air mass comes from a tropical source and consists of warm air. On the other hand, a "warm air mass" may consist of either warm or cold air; the term "warm" in this case is simply a comparison; it says that the air mass, whatever its temperature, *is warmer than the surface it rests upon.* "Warm" is abbreviated as *w,* and the *w* is placed after the original air-mass name. For example, an air mass originating over the Gulf of Mexico in winter is warmer than the land areas of southern United States which it invades. Such a mass is designated as *mTw,* meaning

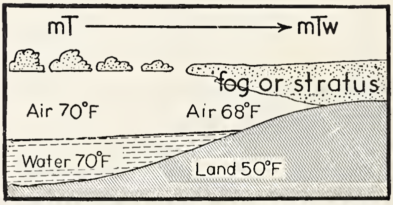


Fig. 8–2. The origin of an *mTw* air mass, in winter, and the weather it causes.

"maritime, tropical, warmer than the surface over which it is passing." Other possible "warm" masses are *mPw, cPw,* and *cTw.*

The colder land or water surface on which a warm air mass rests produces certain important weather effects, regardless of the source of the air mass, and it is in these general effects that the value of this classification lies. Cooling of its air at the bottom tends to form dew, fogs, stratiform clouds, drizzle, or even light rain. There is little or no tendency for convection. Visibility is poor because smoke and dust do not rise. If fogs form, the visibility may become zero.

8. A cold air mass. An air mass that is colder in its lower layers than the surface over which it is passing is called a *cold air mass.* Again, the term "cold" is comparative and is not to be confused with "polar." Cold cannot be abbreviated as *c*, which already means "continental," so *k* is used, from the German word *kalt*, which means "cold." When an air mass from the north is called *cPk*, it indicates that it is "continental, polar, colder" air which is colder than the surface over which it is passing.

All cold air masses, regardless of their source, are being warmed at the bottom and possess certain common characteristics. Warming causes convection. This produces cumulus clouds, windiness, and generally good visibility. If the warming is considerable and enough moisture is present, as when the warm surface beneath is a lake or ocean, the cumulus clouds may grow into cumulonimbus, and showers or thunderstorms may result. Otherwise fair weather is likely to prevail. A dry *cPk* air mass (winter) usually brings fair weather, whereas the more humid *mTk* air mass (summer) will cause showery precipitation.

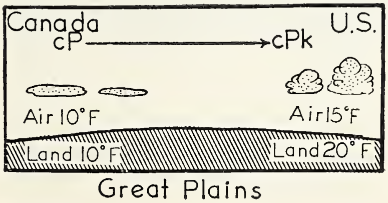


Fig. 8–3. The origin of a *cPk* air mass, and the weather it causes.

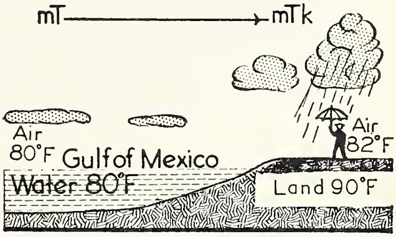
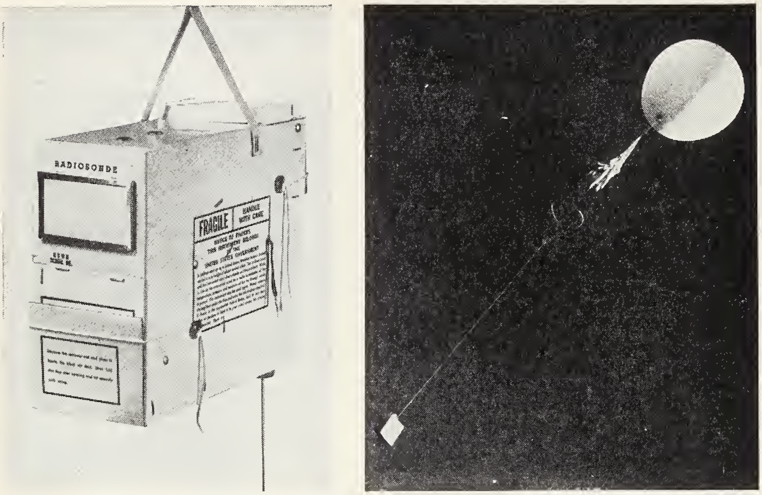


Fig. 8–4. The origin of an *mTk* air mass, in summer, and the weather it causes.

9. Air-mass analysis. The development of the airplane and of radio made the discovery of the existence of air masses not only possible but imperative. In order to insure maximum safety in flight, aviators required information about the upper air as well as about surface weather. But airplanes also represented one means of obtaining information about the upper air. The credit for realizing that large bodies of air, extending far into the troposphere, had uniform temperature and humidity characteristics belongs to a group of Norwegian meteorologists headed by V. Bjerknes and T. Bergeron. The names given to air masses in this chapter are those suggested by Bergeron.

Weather forecasting on the basis of air-mass information and air-mass analysis has proved to be much more accurate than older methods based chiefly



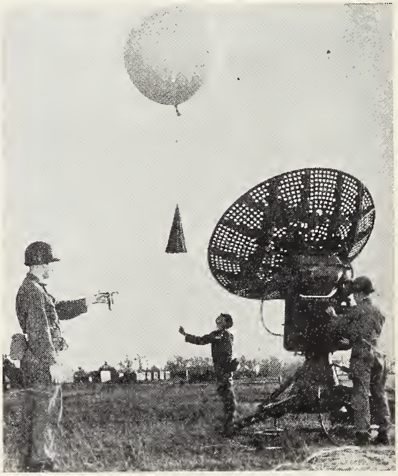
Courtesy Friez Instrument Division
(*a*)

Courtesy U.S. Weather Bureau
(*b*)

Fig. 8–5. The radiosonde: close up (*a*) and in flight (*b*). Note the radio antenna extending below the radiosonde, and the parachute underneath the balloon.

on surface observations. Furthermore, flying-weather information previously not supplied is now available. Information about the upper levels of the troposphere is obtained in many ways, some of which have already been described in the chapters on winds and water vapor. In addition, weather stations take *radiosonde* observations every 12 or 24 hours at about 50 stations throughout the country.

The *radiosonde,* or *radiometeorograph,* is a tiny combination of thermometer, barometer, hygrometer, and radio transmitter. The transmitter automatically emits signals that indicate the temperature, pressure, and relative humidity of the air through which the radiosonde is passing. The radiosonde weighs about 2 pounds and is carried to heights of between 50,000 and 75,000 feet, well into the stratosphere, by a six-foot helium-filled balloon. An automatic radio receiver at the weather station records the signals. Incidentally, while radiosondes are cheap enough to



U.S. Army Photograph

Fig. 8–6. The soldier is holding a new form of radiosonde which is about to be released. At the right is radar equipment for automatically following the flight of balloons used in observing the direction and velocity of upper winds. This recently developed equipment is known as the Rawin (Radio Wind) system.

be expendable, many of them are recovered. When the balloon bursts, a parachute opens and carries the radiosonde safely to the ground.

HAVE YOU LEARNED THESE?

Meanings of: air mass; polar; tropical; continental; humid; source region; warm air mass; cold air mass; radiosonde

Explanations of: origin of an air mass; air-mass sources and direction of movement; operation of the radiosonde

Relations between: air masses and weather; warm air mass and its weather; cold air mass and its weather

Expression of: air mass names by abbreviations and vice versa

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) Define air mass, and explain your definition. (*b*) Explain how air masses can be "discovered" on a weather map.

2. (*a*) How does an air mass originate? (*b*) How does an air mass acquire uniform temperature? uniform humidity?

3. Name each of the following air masses, state its characteristics, and explain why it has these characteristics: *cP; mP; cT; mT.*

4. (*a*) What is a source region? (*b*) In which source region does each of these air masses originate: *cP; mP; mT; cT?* (*c*) In what directions do air masses move? Why?

5. Give a brief description of weather in each of the following air masses in summer or winter: *cP; mP; mT.*

6. What three factors determine the exact weather in an air mass? Explain the effect of each factor.

7. (*a*) Define and explain what a warm air mass is. Describe an example or illustrate with a diagram. (*b*) Explain what kind of air mass each of the following is: *mPw; cPw; cTw.* (*c*) Explain why certain weather phenomena are true of all warm air masses. List these phenomena.

8. (*a*) Define and explain what a cold air mass is. Illustrate in words or diagram. (*b*) What do the following symbols mean: *cPk; mTk; mPk?* (*c*) Explain why certain weather phenomena are true of all cold air masses. List these phenomena. (*d*) How is the weather in *cPk* air likely to differ from that in *mPk* air?

9. (*a*) For what are Bjerknes and Bergeron noted in meteorology? (*b*) What connection is there between the development of the airplane and the discovery of air masses? (*c*) Describe the radiosonde. What three weather elements does it measure?

GENERAL QUESTIONS

1. In what directions would polar and tropical air masses move in the Southern Hemisphere? Why?

2. How will weather in an *mPw* air mass differ from that in a *cPw* air mass?

3. How will *mTw* weather differ from *cPw* weather?

4. How may *mPk* weather differ from *mTk* weather?

5. What kind of thermometer is the radiosonde likely to carry? what kind of barometer? hygrometer? Why?

6. Why should the radiosonde balloon burst at very high altitudes? What determines how high it goes before bursting?

STUDENT ACTIVITIES

1. Identifying air masses from local weather phenomena

2. Identifying air masses in newspaper weather maps

3. Checking identifications of local masses with weather office maps.

4. Studying such characteristics of air masses (on weather office maps) as temperature, dew point, visibility, clouds at various levels, wind directions, and wind force

5. Visiting a weather station to see instruments used in upper-air observations

SUPPLEMENTARY TOPICS

1. North American Air Masses
2. The Working of the Radiosonde
3. More About Cold Air Masses
4. More About Warm Air Masses
5. More About Source Regions
6. Why Air Masses Travel

See list of suggestions for further reading at the end of Chapter 1.

Chapter 9

FRONTS AND THEIR WEATHER

1. What a front is. Air masses travel across the country in a generally eastward direction. At any given moment there may be several different air masses on the surface of southern Canada and the United States following each other from west to east. The *surface* that marks the rear of one mass and the front of the one following it is called a *frontal surface.* The *line* along which that surface meets the ground is called a *front.* It is common practice to use the word *front* for either the surface or the line, so a front is usually defined as a *boundary between two air masses.*

Figure 9–1 shows what a frontal surface would be like if two air masses of different temperature could stand side by side, like heaps of sand and cement, without mixing. But cold air is denser and heavier than warm air, and air can flow. The cold air flows under the warm air, forcing the lighter warm air up and over it, as shown in Figure 9–2. This is just what would happen with water and oil, or with any two liquids of different density. Were it not for the earth's rotation, the frontal surface would become perfectly horizontal, and the warm air would simply lie on top of the cold air. Actually the frontal surface has a very gentle slope that averages about one mile in 100 miles, but may be as steep as one mile in 40, or as gentle as one mile in 200. The cold air slides in under the warmer air like a gigantic thin wedge. Figure 9–3 shows a frontal surface of average

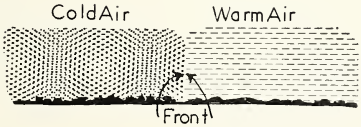


Fig. 9–1. What a frontal surface would be like if air did not flow.

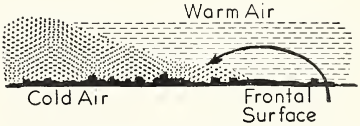


Fig. 9–2. The shape taken by a frontal surface as the cold air flows under the warm air.

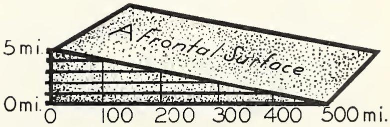


Fig. 9–3. Diagram showing the average slope of a frontal surface. The vertical scale is greatly exaggerated.

slope. In diagrams of frontal surfaces the vertical scale is always exaggerated; otherwise the very gentle slopes of these surfaces would hardly show.

2. The importance of fronts. Since a front is the boundary between two air masses, *when a front passes a particular place it invariably means a change of weather.* The greater the difference between the air masses, the greater the change in weather. For example, if *mT* air is replaced by *cP* air, it will mean the end of a warm, humid spell and the beginning of a cool or cold dry spell. Another feature of great importance is that *fronts are almost always accompanied by precipitation.* The reason for this is the fact that at a frontal surface warm air is rising in great quantities and to great heights, and rising air means precipitation. As will be seen later, this precipitation sometimes precedes and sometimes follows the actual passing of the front on the ground.

3. Locating a front. To locate a front, all that is necessary is to find where one air mass ends and the next one begins. An airplane pilot flying through a front may not actually see it, but he can hardly escape the fact that the weather undergoes certain definite changes as he leaves one air mass and enters the next. In similar fashion, a meteorologist in his office can deduce the position of a front on a weather map by noticing where sharp changes of weather occur. The most noticeable changes, all of which are illustrated in Figure 9-4, are as follows:

(1) Temperatures are usually distinctly lower on one side of a front than on the other.

(2) Wind directions are sharply different on opposite sides of a front.

(3) Wind velocities are usually higher on one side of the front than on the other.

(4) Dew points differ greatly from one side to the other.

(5) Air pressure is higher in the colder air.

Since air pressure usually changes abruptly as the front is crossed, the isobars of the weather map make sharp bends or kinks at the front. These kinks represent the easiest and surest features for locating the front on the weather map. They always point toward the center of high pressure, or away from the center of low pressure.

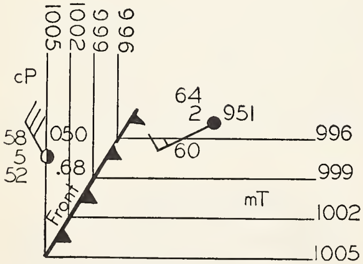


Fig. 9–4. The weather on one side of a front is different in many important respects from that on the opposite side. Isobars bend sharply at a front.

4. Kinds of fronts; symbols; direction. Meteorologists classify fronts into three different kinds according to the motion of the air masses involved. If cold air is pushing warmer air ahead of it across the country, the front is called a *cold front.* If warm air is pushing colder air ahead of it, the front is a *warm front.* If neither air mass is being displaced, the front is said to be *stationary.* Fronts may also be defined as follows: (1) A cold front is the leading edge of an advancing mass of cold air; (2) a warm front is the leading edge of an advancing mass of warm air; (3) a stationary front is the boundary line between two air masses that are not moving. Since masses of cold polar air usually invade from the northwest, cold fronts usually move to the southeast. Similarly, since masses of warm tropical air usually come from the southwest, warm fronts generally move northeastward.

A fourth kind of front, the *occluded front*, is really a combination of cold and warm fronts. It will be fully explained in Topic 8, but may now be defined as the front that results when a cold front overtakes a warm front. Figure 9–5 shows the weather-map symbols for fronts. In each case the solid half-circles (for warm fronts) and the solid triangles (for cold fronts) point in the direction of the front's movement.

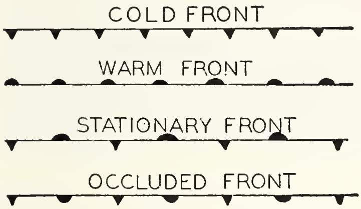


Fig. 9–5. Symbols used to show fronts on weather maps.

5. Warm-front weather. Warm fronts, along which warm air is replacing colder air, have comparatively gentle slopes. The average slope is about one mile in 100, but in some cases it is as little as one mile in 200. This means that the warm air must travel from 500 to 1000 miles in order to rise 5 miles. (See Figure 9–3.) The gently rising air, unless it is very dry, soon reaches its dew point as it cools by expansion, and a vast system of clouds forms in the warm air above almost the entire frontal surface. The clouds are largely *stratiform*, and they may extend for a thousand miles ahead of the front on the ground. Thin icy cirrus clouds lead the procession at the highest level. Behind them comes a veil of cirrostratus clouds which may cause halos around the sun or moon and make it possible for an observer to forecast the coming of the warm front from 24 to 36 hours in advance. As the warm air increases in quantity, the thick, middle-height altostratus clouds appear, almost screening out the sun or moon, and precipitation becomes imminent. Finally, heavy low nimbostratus cloud masses turn the sky

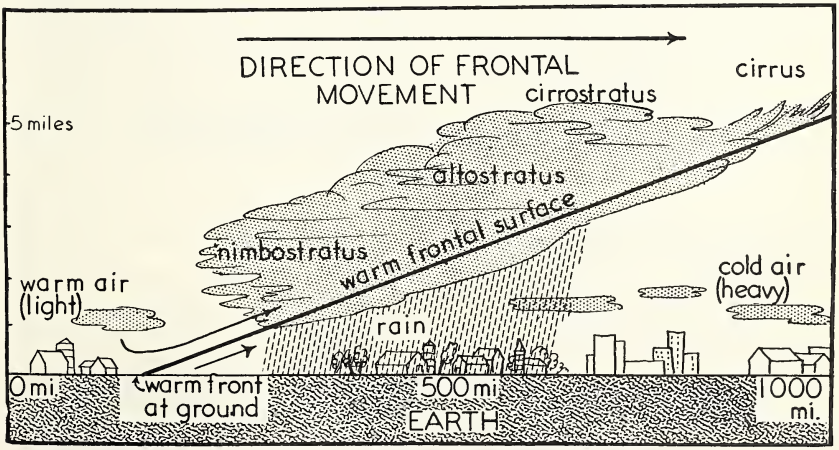


Fig. 9–6. A vertical cross section through a warm front cloud system and its air masses.

gray and steady precipitation sets in, extending for hundreds of miles *ahead of the front on the ground,* and over a width of at least 100 miles.

Figure 9–6 shows the cloud system of a warm front in cross section. Since this is a warm front, warm air is pushing cold air ahead of it, usually from southwest to northeast, and the entire cloud system is traveling in that direction. At any particular locality, then, the approach of a warm front is indicated by the sequence of clouds described above. Precipitation continues until the front on the ground passes the locality (see Figure 9–6). When this front passes, the mass of warm air arrives, and many weather elements change. The temperature rises, the wind shifts, the pressure falls, the rain ends, and the sky undergoes partial clearing. Until the next front comes along, air mass weather prevails. See Chapter 8.

6. Weather of a cold front. Cold fronts are steeper than warm fronts, because the advancing cold-air winds move faster at higher altitudes, so the top of the frontal surface tends to catch up to the bottom and become more nearly vertical. Even so, the slope is small, ranging from one mile in 40 miles to one mile in 80. Cold fronts move faster than warm fronts because heavy cold air can displace warm air faster than warm air can displace cold air. The direction of movement of cold fronts, like that of the polar air masses which they lead, is usually from northwest to southeast.

Again, it is the rising warm air which is cooled to its dew point and forms clouds. This time, however, the slope is often steep enough to cause convection and *cumuliform* clouds, and the cloud system *extends behind the ground front as well as ahead of it.* Since most of the rising warm air is found within a rather short distance of the steep front, the cloud system is much less extensive than in the warm front, usually covering between 200 and 300 miles. There is no long warning sequence of approaching precipitation as in the warm front. The cumulonimbus clouds arrive rather suddenly, and precipitation is showery, heavy, and of comparatively short duration. Thunderstorms are common.

When the front passes on the ground, the changes of weather which occur are usually much more striking and abrupt than those that accompany the passage of the warm front. Temperatures fall rapidly as the cold air arrives. The wind

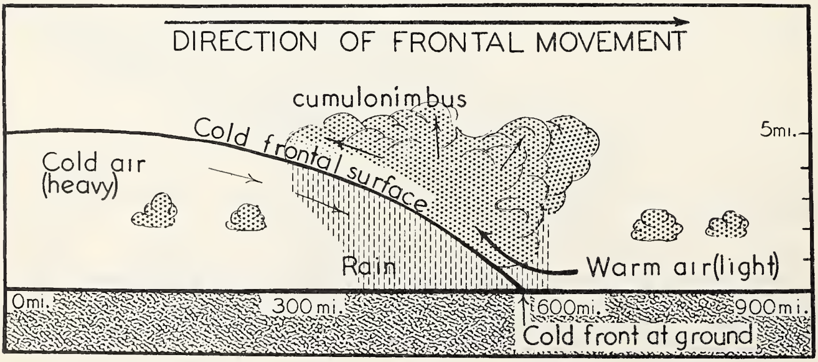
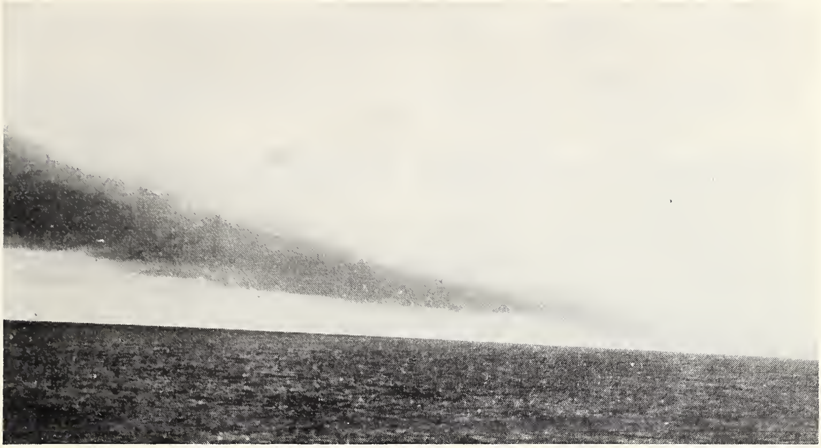


Fig. 9–7. A vertical cross section through a cold front cloud system and its air masses.



B. G. Thompson, U.S. Weather Bureau

Fig. 9–8. The squall line along a cold front.

rises in velocity, often becoming gale-like, and usually shifts sharply from a southerly direction to a northerly one. Air pressure rises. *The rain continues for a short time after the front passes.* When the rain ends, partial clearing occurs, and once again air-mass weather prevails until the next front arrives.

Because of the sharp changes in wind direction that take place along them, cold fronts are often called *wind-shift lines.* When extremely humid *mT* air is being pushed forward by the cold front, a gigantic continuous line of thunderstorms may form all along the front, hundreds of miles in extent. This line of storms is known as a *squall line* or *line squall,* and marks the visible edge of the cold-air "wedge."

7. Stationary fronts. Frequently a cold front or a warm front slows down until it stops moving entirely. The air masses on either side are then said to be separated by a *stationary front.* Although the air masses are not changing their positions relative to the ground, warm air is still rising above cold air. The slope of the stationary air mass boundary tends to become as gentle as that of a warm front. Consequently, the weather of a stationary front is approximately the same as that of a warm front. After remaining stagnant for a time, all or part of a stationary front may resume motion in either direction. Where the warm air advances, it is again a warm front. Where the cold air advances, it becomes a cold front.

8. Occluded fronts. When a tropical air mass lies between two polar masses, all moving eastward, the front of the tropical mass is a warm front, while behind it is a cold front (see Figures

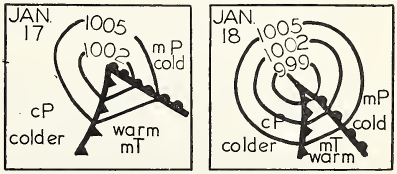


Fig. 9–9. The development of an occluded front, (cold front type), as seen on the weather map in two successive days.

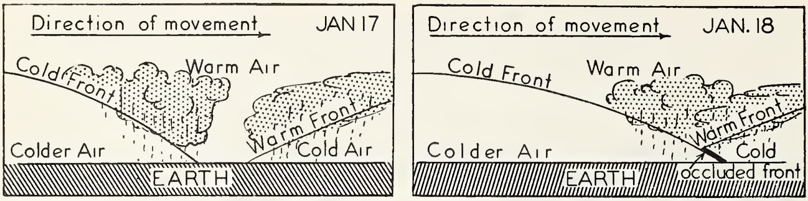


Fig. 9–10. Development of an occluded front (cold front type) as seen in vertical cross section in two successive days. This is the same front as is shown in Figure 9–9.

9–9 and 9–10). But cold fronts move faster than warm fronts, and often actually overtake them, forming *occluded fronts.* (*Occluded* means "closed in," indicating that one front has "closed in" on the other.) In effect, this means that the second polar air mass has overtaken the first one, and the lighter tropical air mass has been lifted completely off the ground. When such a system approaches a locality, the weather it brings is a combination of warm front and cold front weather, in that order. In this case, however, the passing of the front on the ground does not bring a change from warm air to cold air or the reverse, as with warm and cold fronts. Instead, the change is from one body of cold air to another.

If the second polar mass is colder than the first polar mass, its front (the cold front) underrides and lifts the warm front, forming a cold front type of occlusion, in which the weather is mostly like that of a cold front. If the second mass is not as cold as the first, its front (the cold front) rises above the heavier air ahead of it, leaving the warm front reaching to the ground. In this case, known as a warm front type of occlusion, warm front weather predominates. (See Figures 9–10 and 9–11.)

Above the ground, the two fronts are separate and distinct, and an airplane flying through this system at a high enough altitude will still pass through two fronts and three air masses. But as occlusion continues, the warm air is lifted higher and higher, the air masses merge, and eventually the fronts disappear as the differences between the air masses gradually diminish.

9. Summary. In all Temperate Zone climates, in both the Northern and the Southern Hemisphere, the most important changes of weather, other than those due to seasons, are the ones brought about by the passage of fronts. All fronts —warm, cold, stationary, or occluded— are almost certain to bring rain with them. Warm front rains are steady and

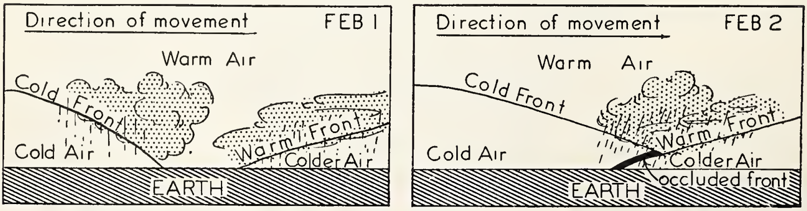


Fig. 9–11. Development of an occluded front (warm front type) as seen in vertical cross section in two successive days.

extensive and are usually associated with stratiform clouds. They precede the ground position of the front. Cold front rains are showery, are of short duration, and are usually associated with cumuliform clouds. Cold front rains come both before and after the passage of the front at the ground. Cold fronts move more rapidly than warm fronts and cause greater changes of weather.

HAVE YOU LEARNED THESE?

Meanings of: frontal surface; front; warm front; cold front; occluded front

Diagrams and descriptions of: all frontal symbols; vertical cross sections through warm front and cold front cloud systems; formation of an occluded front; frontal slopes

Explanations of: meaning of front; importance of fronts; location of fronts

Relations between: warm fronts, precipitation, and weather changes; cold fronts, precipitation, and weather changes

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) Explain what a frontal surface is. (*b*) Explain what a front is. (*c*) Describe the average slopes and relative positions of warm and cold air in any front.

2. (*a*) Explain why precipitation is almost always associated with a front. (*b*) Why does the passing of a front mean changes in weather?

3. (*a*) What differences in weather can be seen on opposite sides of a front? (*b*) How do isobars show the location of a front? (*c*) Compare the temperature, pressure, wind direction, wind velocity, dew point, and cloudiness on both sides of the front in Figure 9–4.

4. (*a*) Define or explain the four kinds of fronts and draw the symbol for each. (*b*) How do the symbols indicate the direction in which fronts move? (*c*) In what direction do cold fronts move? Why? (*d*) In what direction do warm fronts move? Why?

5. (*a*) Describe the slope of a warm front. (*b*) Describe the cloud system of a warm front. (*c*) Describe the kind and extent of warm front precipitation. (*d*) Show the cloud system of a warm front in a diagram. (*e*) What weather changes occur as a warm front passes by? (*f*) Why are cirrostratus clouds an aid to the amateur weather forecaster?

6. Using a diagram as part of your explanation, describe the slope, cloud system, precipitation, and weather changes associated with a cold front and its passage.

7. How does a stationary front originate? What kind of weather does it have?

8. (*a*) How does an occluded front originate? (*b*) Distinguish between the two kinds of occluded fronts and their weather. (*c*) How may an occluded front eventually disappear?

9. Summarize the importance of fronts in the temperate zone. Briefly contrast warm fronts with cold fronts.

GENERAL QUESTIONS

1. Can you tell from a weather map which way an occluded front is moving? Explain.

2. What must be the direction of movement of warm fronts and cold fronts in the Southern Hemisphere? Explain.

3. How would the weather of a rapidly moving cold front differ from that of a slow moving one?

4. Describe the probable sequence of weather in a warm front type of occlusion.

5. What kind of air-mass weather is likely to follow the passing of a warm front? of a cold front?

6. Why should there be small cumulus clouds in the cold air in Figure 9–7?

7. Why should there be stratus clouds in the warm air behind the warm front in Figure 9–6?

STUDENT ACTIVITIES

1. Studying the characteristics of fronts on weather maps
2. Making three-dimensional models of frontal cloud systems
3. Observing and describing the passage of a front
4. Photographing typical frontal clouds
5. Forecasting the arrival of a warm front by its cloud sequence

SUPPLEMENTARY TOPICS

1. Frontogenesis: The Origin of Fronts
2. Frontal Zones of the World
3. Frontolysis: The Disappearance of Fronts
4. Frontal Layers of Transition
5. Fronts and Wind Characteristics
6. Fronts and Air Stability
7. Fronts and Mountains
8. Fronts and Flying Weather

See list of suggestions for further reading at the end of Chapter 1.

Chapter 10

CYCLONES, ANTICYCLONES, AND THUNDERSTORMS

1. Definitions of cyclones and anticyclones. Before the existence of air masses and fronts was discovered, weather forecasting was based largely on the knowledge that areas of low air pressure were usually associated with cloudiness and precipitation, while areas of high air pressure were associated with fair weather. Low-pressure areas surrounded by closed isobars were named *cyclones* or *lows.* High-pressure areas surrounded by closed isobars were named *anticyclones* or *highs.* Studies of thousands of cyclones and anticyclones gave information about the places of their origin and the courses they generally followed as they moved across the country. With this information the forecaster was able to calculate the probable positions of lows and highs for a day in advance, and thereby predict the next day's weather.

Lows and highs appear on weather maps today as they did in years past, and modern meteorologists still make use of their movements in determining the weather forecast. But our knowledge of the origin and nature of these formations has improved immensely, particularly with respect to their structure above the earth's surface and their relation to air masses and fronts. The result has made possible better and longer-range forecasts.

2. The origin of a cyclone. In 1918 the young Norwegian meteorologist J. Bjerknes (son of V. Bjerknes) announced his findings, after long research, that cyclones, or lows, appeared to consist of portions of air masses of contrasting temperature separated by fronts. At the same time he offered his *wave theory of cyclone development* to account for his findings. This theory is summarized in the six diagrams of Figure 10–1. Each diagram represents a stage in the development for which actual illustrations can be found on weather maps. The solid lines are isobars, the arrows show wind directions, and the usual symbols indicate warm, cold, stationary, and occluded fronts. Stage *a* shows a stationary front between the polar northeasterly wind belt and the warmer prevailing southwesterly wind belt. This permanent front between the wind belts is known as the *polar front.* In stage *b*, a "wave" develops as the warm air bulges into the cold air, forming a warm front at the right where it displaces cold air, while behind it is a

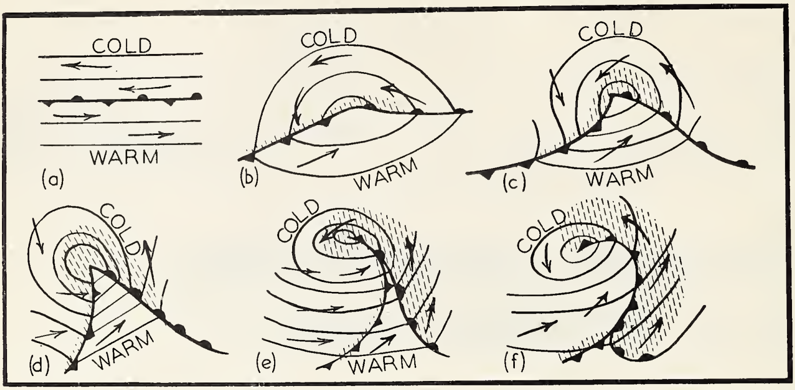


Fig. 10–1. The development of a cyclone, according to the wave theory. See Topic 2 for explanation.

cold front where the cold air advances. In stage *c* the cyclone is fully developed. In this stage it is known as a typical cyclone, and consists of a *warm sector* nearly surrounded by colder air. In *d*, the cold front starts to overtake the warm front; in *e* occlusion begins. In *f*, the warm sector is almost completely above the ground, occlusion (lifting of the warm air) is almost complete, and it is but a short time before the warm and cold air are so thoroughly mixed that the fronts will disappear and the cyclone vanish from the weather map.

The development from stage *a* to stage *c* takes only 12 to 24 hours, while from *c* until the cyclone is completely occluded usually takes 3 days or more.

3. The typical cyclone of middle latitudes. Figure 10–2, center, shows a detailed diagram of a typical cyclone like that of stage *c* in Figure 10–1. It shows plainly what the relations are between the cyclone as it was known before 1918 and the fronts and air masses it is now known to include. The lower part of Figure 10–2 shows a vertical section south of the cyclone center along line *CD*, where the warm sector is on the ground between the two fronts, with cold air ahead of and behind it. In this area the passage of a cyclone would consist of: (1) the rainy passage of a warm front, (2) the passage of a clearing mass of warm air, (3) the rainy passage of a cold front.

The upper part of Figure 10–2 shows a vertical section through the cyclone along the line *AB*, north of the cyclone center. Here the warm air is above the surface. Rain from the elevated fronts is continuous, and there is no change from cold to warm air at the ground.

The word "cyclone" means "whirl," and the cyclone is so named because of the whirling pattern made by the winds that circulate around its center. In accordance with Ferrel's Law, these winds blow to the right of the cyclone center in the Northern Hemisphere, producing a *counterclockwise* whirl. In the Southern Hemisphere, where deflection is to the left, cyclones have a *clockwise* whirl.

The thin black lines of the cyclone are its isobars, with lowest pressure at the center. The sharp kinks in the isobars indicate the locations of the two fronts and account for the sharp changes in wind direction that occur at the fronts.

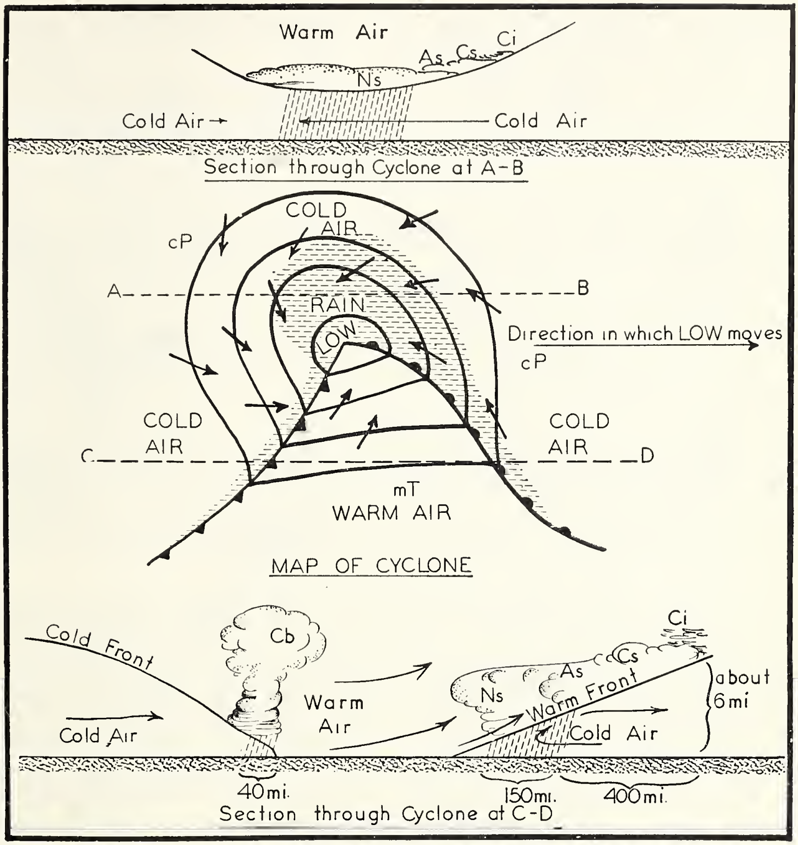
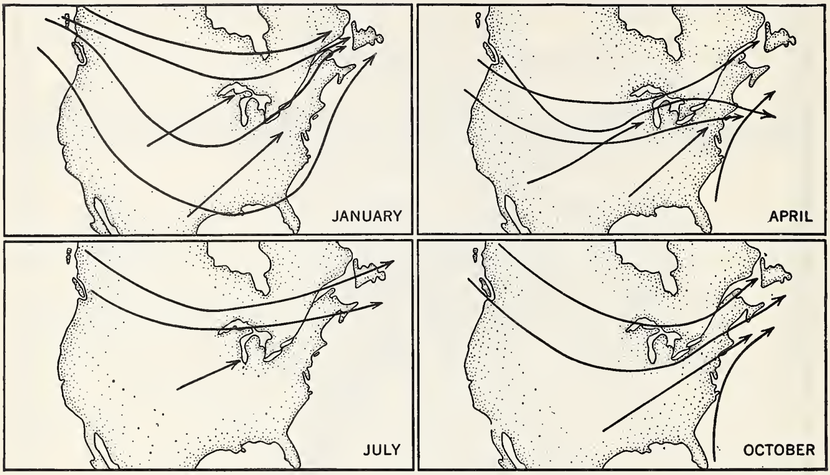


Fig. 10–2. A typical cyclone on a weather map. Above and below it are shown vertical sections north and south of the cyclone center.

The diagram also shows the extent of the cloud areas associated with the fronts.

4. Sources and tracks of cyclones that affect Canada. The cyclones that cross and influence Canada originate mainly in the west of the continent. The cyclones that reach the Pacific coast rarely cross the Western Cordillera but seem to start others in Alberta and Montana. Following the tracks shown in Figure 10–3, almost all Canadian cyclones eventually move towards the east. Cyclones starting in the United States tend to move northeast in the eastern part of the country and there is a concentration of storm paths in the Great Lakes-St. Lawrence area. In winter, cyclones are better developed, move faster, and are more frequent than in summer. Their rate of movement across the country in winter is about 700 miles a day, and in summer 500 miles a day.

5. Hurricanes; tropical cyclones. *Hurricanes are tropical cyclones.* Like middle-latitude cyclones, they are storm areas of low air pressure surrounded by circular isobars; winds spiral counter-



After Miller

Fig. 10–3. Principal tracks of cyclones (lows) in the United States and southern Canada.

clockwise into their centers in the Northern Hemisphere and clockwise in the Southern Hemisphere; air rises at their centers; they are areas of heavy precipitation. But in many other respects they differ greatly from middle-latitude cyclones. They are smaller but are much more intense, the average diameter being from 200 to 400 miles, as contrasted with the 1000 mile diameters of typical middle-latitude cyclones. Their central air pressure is much lower, their pressure gradients much steeper, their wind velocities much higher, often exceeding 100 miles per hour, and their rains much heavier. A hurricane has no fronts, and it has a peculiar calm, clear central area, believed to be caused by descending currents. This area, averaging 15 miles in diameter, is known as the "eye of the storm."

Tropical cyclones are known by various names. In the West Indies they are called *hurricanes*, in the Indian Ocean *cyclones*, in the China Sea *typhoons*, and in the Philippine Islands *baguios*. Much of the damage done by these great storms is the result of the gigantic sea waves generated by them along coastal areas, especially when they coincide with the arrival of high tides. The famous Galveston, Texas, hurricane of September 8, 1900, took the lives of over 6000 people, many of whom were drowned by great waves that rolled over the offshore bar on which Galveston is built.

6. Sources and tracks of tropical cyclones. All tropical cyclones originate on the western sides of the oceans in the doldrums, between 6° and 20° latitude in both hemispheres. This includes the West Indies and Caribbean area, the China Seas of East Asia, the southern Indian Ocean, and the ocean areas adjacent to east Australia and east Africa. The only part of the doldrums in which tropical cyclones do not occur is the South Atlantic area. They are most likely to develop when the doldrums are farthest north or south of the Equator.

The tracks of tropical cyclones are shaped like parabolas (see Figure 10–4). After forming in the doldrums, these cyclones move westward and away from the Equator through the trade-wind belts at a slow, drifting pace of from 6 to 12 miles an hour. After passing slowly through the horse latitudes, they speed up and turn eastward, continuing polewards with the prevailing westerly winds at speeds of from 20 to 30 miles an hour.

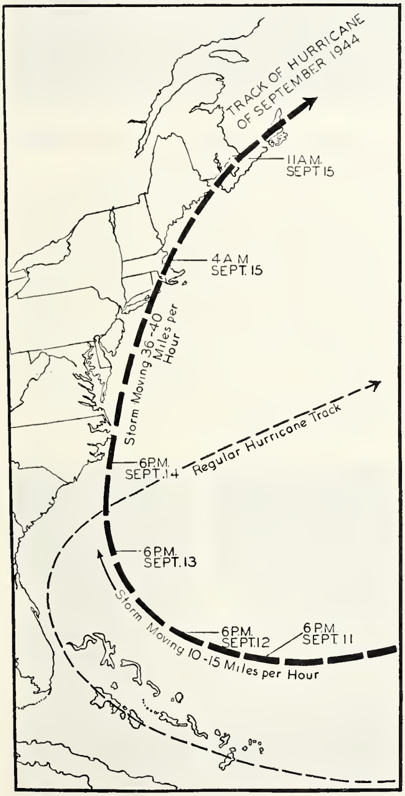
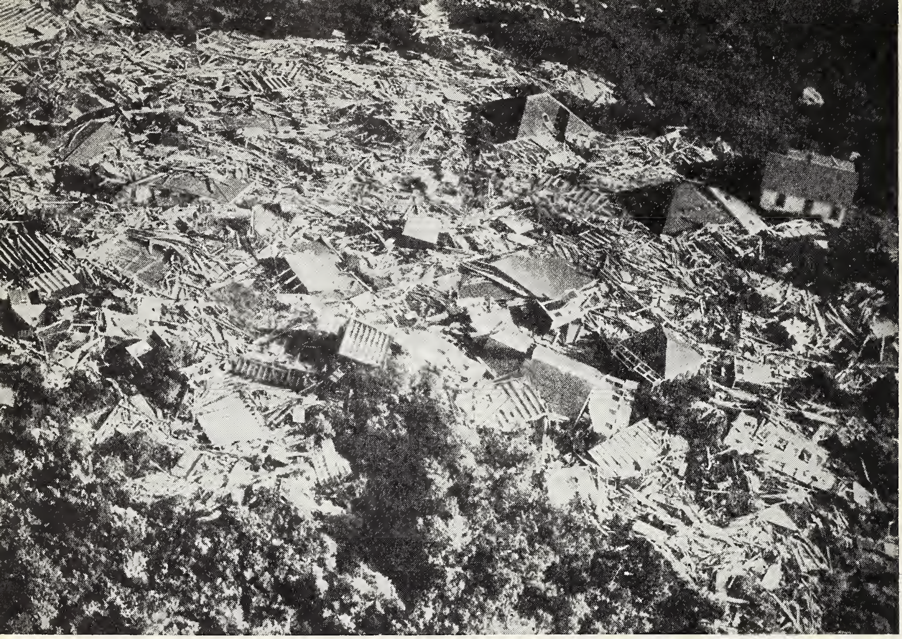


Fig. 10–4. The track of the great hurricane of September 1944, compared with the usual track of West Indian hurricanes.

West Indian hurricanes are most frequent in late summer and early fall. Hurricanes developing at this time, when the doldrums are farthest north, are the ones most likely to reach the United States. Many of them strike Florida and southeastern United States before blowing out to the Atlantic Ocean. In recent years a few have penetrated north to New England and southeastern Canada; these become modified as they continue northward through the westerlies, they may still arrive as storms far more violent than any ordinary middle-latitude cyclone. Two such storms smashed through the northeastern states on September 21, 1938, and September 14, 1944. Their fierce winds, waves, and high tides combined with their torrential rains and floods to cause many millions of dollars worth of property damage and the loss of many lives.

7. Tornadoes and waterspouts. *Tornadoes* are the smallest and most violent of all storms. They occur almost exclusively in the United States, chiefly in the Mississippi Valley and the eastern half of the Great Plains. They occasionally develop in southern Canada as in the tornado of southwest Ontario in May, 1953. Also called *twisters,* tornadoes are narrow, funnel-shaped, spiral whirls in which wind velocities may reach 300 miles an hour and updrafts may have a speed of over 100 miles an hour. Never directly measured, the air pressure at tornado centers is believed to be very low. Air rushing in to the center cools by expansion below its dew point to form a dense, black, funnel-shaped cloud from which thunder and lightning, heavy rains, and hail almost always are discharged. Tornado clouds hang low from the cumulonimbus thunderclouds with which they are associated (usually in cold front line squalls between *mP*

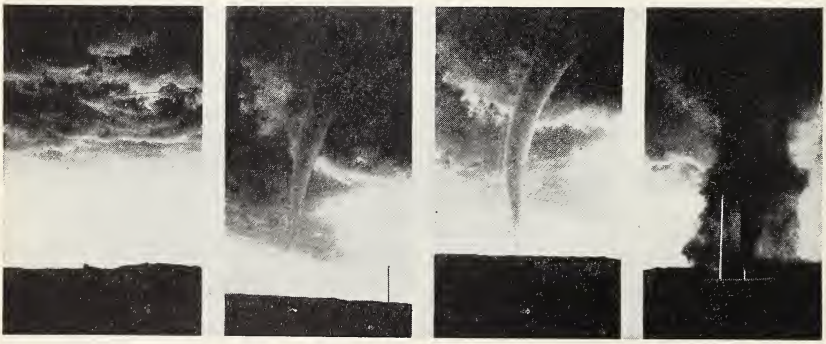


Worcester Telegram, *U.S. Weather Bureau*

Fig. 10–5. Houses turned to matchwood. What the great hurricane of September, 1938 did to the town of Mattapoisett, on the shore of Buzzards Bay, Massachusetts.

and *mT* air masses), frequently touching the ground, and causing destruction through the action of both their violent winds and their suction-producing vacuum centers.

Tornadoes vary in diameter from a few hundred feet to a mile. Their paths are erratic and unpredictable. They travel at rates of from 25 to 40 miles an hour, passing any particular point with a deafening roar in but a few seconds. Their life spans are measured in hours, and their paths of destruction seldom exceed 300 miles in length. Tornadoes that occur over bodies of water are called *waterspouts*.



U.S. Weather Bureau

Fig. 10–6. Four views of a destructive tornado at Gothenburg, Kansas. On a 30-mile path this tornado killed one person, injured five, and destroyed property valued at $200,000.

The worst tornado disaster in United States history was that of March 18, 1925, in Missouri, Illinois, and Indiana, when 719 persons were killed, more than 3000 injured, and property damage exceeded $25,000,000. In the tornadoes of March 21–23, 1952, in Arkansas, Tennessee, Missouri, Mississippi, Alabama, and Kentucky, nearly 250 persons were killed. Destructive tornadoes struck the United States again in May and June of 1953. One series of tornadoes caused 143 deaths in Ohio and Michigan. Others did great damage in Texas. But the most unusual one was that which caused nearly 100 deaths and more than $50,000,000 in property damage in Worcester, Massachusetts and neighboring towns, where tornadoes are almost unheard of. Tornadoes are most frequent in spring and early summer.

8. Thunderstorms. Thunderstorms are local, small-area storms generated by cumulonimbus clouds. They are accompanied by lightning, thunder, heavy rain, and strong gusts of wind. Hail often occurs at the beginning of a thunderstorm. Individual thunderstorms rarely last more than two hours, but it is quite possible for several thunderstorms to strike at different times of the same day.

Cumulonimbus clouds and their thunderstorms are the result of the strong upward movement of warm moist air, a movement which may be produced principally in two ways. Air-mass thunderstorms occur within an air mass on summer afternoons when warm moist air is strongly heated at the earth's surface and powerful convection currents are developed. These thunderstorms are also called thermal or convectional thunderstorms, and they are likely to be local or scattered in occurrence. (See Chapter 8, Topic 8.) *Frontal thunderstorms* may occur at any time of the year or day in connection with well-developed cold fronts, as previously explained. The line of thunderstorms, known as the *line squall*, may be several hundred miles long and 40 or 50 miles wide. (Figure 9–8).

Figure 10–7 shows the structure of a thunderstorm. Notice in particular: (1) the rising air currents that blow toward the approaching storm; (2) the strong vertical drafts within the cloud, where hail is formed; (3) the downdrafts under the cloud; (4) the violent squall wind between (1) and (3). As a result of the tearing apart of large raindrops by the cloud's updrafts, frictional electric charges are produced with the cloud. When the electricity discharges, either

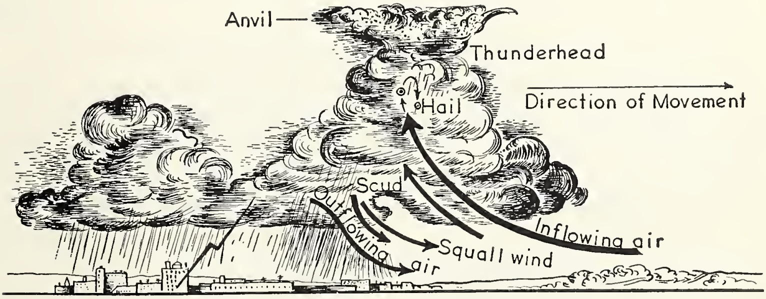


Fig. 10–7. The structure of a thunderstorm.

within the cloud itself, to another cloud, or to the ground, a lightning flash is produced. The sudden expansion of the air heated by the lightning flash causes a tremendous air wave which is heard as thunder. So-called "heat lightning" is the flash of lightning from a storm too distant to be heard. Since lightning is seen instantaneously, while sound takes about 5 seconds to travel a mile, it is a simple matter to calculate one's distance from a thunderstorm.

9. Weather in anticyclones. *Highs,* or *anticyclones,* usually appear on weather maps as a series of smooth circular isobars, in contrast with the kinked oval isobars of lows or middle-latitude cyclones. Unlike a low, a high represents a single air mass. Since the air pressure in a high is highest at the center, winds blow outward to form a whirl that is clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. Isobars are generally farther apart than in lows, and pressure gradients and wind velocities are correspondingly smaller (see Figure 4–2). Bright, clear weather is usually present throughout anticyclones, which often have a diameter far in excess of 1000 miles. Descending dry air at the anticyclone center is believed to account for its fair weather. As a rule the only important forms of condensation are the heavy dew, frost, and radiation fogs that may form at night in the still, clear air near the surface. Occasionally, however, rain, drizzle, and cloudy skies do develop in the southern portions of anticyclones.

Anticyclones may originate in polar or tropical regions, bringing cold or warm weather respectively. Like cyclones, they travel eastward or southeastward in Canada, but at lower average speeds. Those that come from the north bring cold waves in winter and cool clear weather at other times of the year. Those that come from the south bring mild weather in winter and hot dry spells in summer.

HAVE YOU LEARNED THESE?

Meanings of: high, low, cyclone, anticyclone, tropical cyclone, hurricane, tornado, waterspout, thunderstorm

Diagrams and descriptions of: a typical cyclone; a typical anticyclone; a thunderstorm

Explanations of: weather in a cyclone; weather in a tropical cyclone; weather in an anticyclone; tornadoes; thunderstorms; lightning and thunder

Relations between: tropical and middle-latitude cyclones; tornadoes, thunderstorms, and lows

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Define cyclone and anticyclone. Explain how they were used in making weather forecasts before air masses were discovered.

2. What is the polar front? Explain, according to Bjerknes' theory, how a cyclone develops. Use diagrams.

3. (*a*) Describe the weather that would result from the passage of a cyclone in an area: (1) south of the cyclone center; (2) north of the cyclone center. (*b*) Describe the wind pattern of a cyclone: (1) in the Northern Hemisphere; (2) in the Southern Hemisphere. (*c*) How are the fronts of a cyclone located on the weather map? (*d*) Draw a diagram of a typical cyclone as it appears on the weather map.

4. (*a*) From Figure 10–3, describe the three principal places of origin of cyclones in North America and their paths across the country. (*b*) How do winter cyclones differ from summer cyclones?

5. (*a*) How do tropical cyclones resemble cyclones in middle latitudes? (*b*) How do tropical cyclones differ from those in middle latitudes? (*c*) What are the various names given to tropical cyclones?

6. (*a*) Where do tropical cyclones originate? (*b*) What general path do they follow? At what speeds do they travel? (*c*) When are hurricanes most likely to reach the United States? Why?

7. (*a*) Describe the place of occurrence, appearance, and life history of a tornado. (*b*) In what parts of the United States are tornadoes most frequent? (*c*) What is a waterspout? (*d*) When do tornadoes occur?

8. (*a*) What are thunderstorms? Describe their structure. (*b*) How do the two different types of thunderstorms originate? (*c*) What is the cause of lightning? of thunder? (*d*) How can the distance to a thunderstorm be calculated? Give an illustration. (*e*) What is heat lightning?

9. (*a*) Describe the direction and strength of winds in an anticyclone. (*b*) What kind of weather characterizes an anticyclone? Why? (*c*) Compare the movements of anticyclones and cyclones. (*d*) What is the relation between the place of origin of an anticyclone and the weather it brings?

GENERAL QUESTIONS

1. In Topic 4 it is said that "in winter cyclones are better developed, move faster . . . than in summer." Why should this be?

2. What is the meaning, in terms of air masses, of the fact that hurricanes have no fronts?

3. What accounts for the heavy precipitation in tropical cyclones?

4. Why do the walls of a building blow out rather than cave in when struck by a tornado?

5. If thunder is heard 10 seconds after lightning is seen, how far away is the storm?

6. Why should heavy frosts, dew, and fogs be associated with highs?

7. Why do highs and lows follow a general west-to-east course across the country?

8. In what kind of air mass are air-mass thunderstorms most likely to develop?

STUDENT ACTIVITIES

1. Forecasting the weather from the rise and fall of the barometer alone

2. Tracking lows and highs on consecutive weather maps

3. Checking the wind directions about low and high centers on weather maps

4. Making observations of wind speed and direction before, during, and after a thunderstorm

5. Photographing growing cumulonimbus clouds and lightning

6. Calculating the distance to a thunderstorm by timing the interval between lightning and thunder

7. Studying the relation between air masses and lows and highs, as shown on the weather map

SUPPLEMENTARY TOPICS

1. Old Theories of Cyclone Origin
2. Studies of Cyclone Tracks
3. Tropical Cyclones
4. The Galveston Hurricane
5. S. Ontario Hurricane Hazel, October 1954
6. Tornadoes and Waterspouts
7. Inside a Thunderstorm
8. The Growth of a Thunderstorm
9. The Size of a Thunderstorm
10. Hurricane Hunting

SUGGESTIONS FOR FURTHER READING

Hurricanes, by I. R. Tannehill. Princeton University Press, 1942.

(*Also see list at the end of Chapter 1.*)

Chapter 11

THE CANADIAN METEOROLOGICAL SERVICE AND ITS WORK

1. Weather-map history. It is now more than 150 years since meteorologists began to realize that adequate understanding of the weather could be achieved only by drawing and studying weather maps. A weather map shows the weather conditions that exist over a considerable area at some particular time. To construct such a map requires that many observers record weather data more or less simultaneously and that these data be compiled at some central place. The first weather maps of this kind were made in 1820 in connection with studies of storms, the data being laboriously gathered from many independent observations. On August 8, 1851, the first *daily* weather map was published in England. Receiving its data by telegraph, it showed the weather for 9 A.M. *of the same day*. The Meteorological Service of Canada was established in 1871. Two years later warnings of approaching storms were first received from the United States and from 1876, weather forecasts were issued from Toronto. It was often difficult to distribute forecasts quickly outside the cities, and for a time forecasts were shown on the sides of railway cars by discs.

The Canadian Meteorological Service was at first a division of the Department of Marine and Fisheries, but since 1936 it has been in the Air Services Branch of the Federal Department of Transport. The headquarters is in Toronto, near the University, where there has been a Magnetic and Meteorological Observatory since 1840.

2. Making the weather map. The data for today's weather map are gathered by observers at over 250 stations across Canada, and from observers in the United States, Alaska, and from over 100 ships at sea each day. Over 100 stations report hourly by teletype over a network that covers the country. At all the stations observations are taken at least four times daily, at 1:30 A.M., 7:30 A.M., 1:30 P.M., and 7:30 P.M. Eastern Standard Time. Since 1953 maps have been drawn from the data at the Central Analysis Office in Montreal. These are then transmitted by wire and radio over a facsimile system which reproduces the maps instantaneously and automatically in weather offices across the country where the forecasts are made. In the same way Montreal sends

Doucette, Canada Dept. of Transport

Fig. 11–1. A forecaster analysing the weather map in a Canadian Meteorological Service office.

the forecasts of how the weather map is expected to look in a few hours time. A weather map that is drawn from the observations of large numbers of observers all taken at the same time, is known as a *synoptic* chart since it gives a synopsis, or summary, of the weather, over a large area at one time.

3. The station model. The amount of information plotted on the weather map is almost incredibly large. For each station the following observations are shown: (1) the state of the sky and the present weather; (2) the weather in the past 6 hours; (3) the kind of high, middle, and low clouds and their movements; (4) the ceiling, the height and amount of low clouds, the total amount of clouds; (5) visibility; (6) wind direction and wind force; (7) barometric pressure and the amount and character of pressure change in past 3 hours; (8) temperature and dew point; and (9) precipitation total in past 6 hours.

In order to show this information uniformly, concisely, and in easily interpreted fashion, the weather office arranges it around the station in a form called the *station model.* Where possible, direct readings are given. In all other cases, codes are used. Both station model and codes are based on those of the International Meteorological Office with slight modification. All maps based on the international system can be read by meteorologists of any country, as can the coded information sent by wire or radio. Figure 11–3 shows the complete station model with its explanation. The simpler features of the station model have already been explained in preceding chapters. Figure 11–4 is part of a weather map on which the reading of the station model may be practiced, and air-mass symbols, fronts, lows and highs, and other features studied. Figure

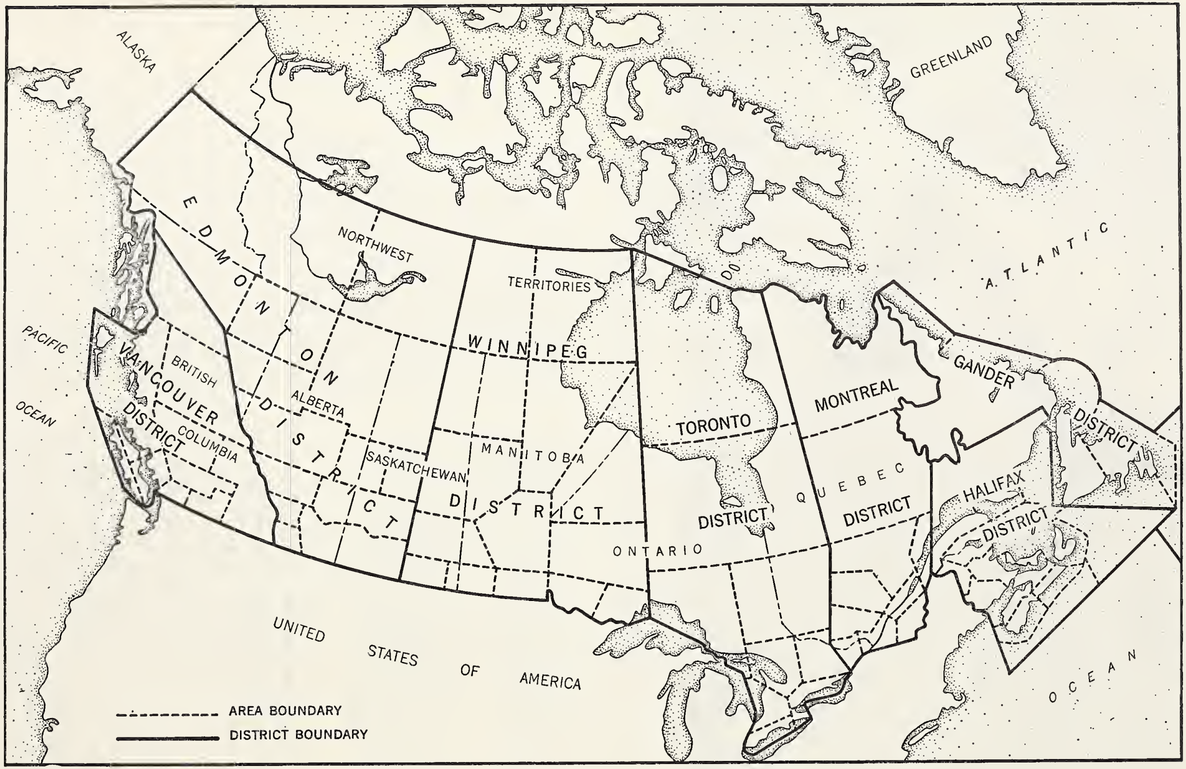


Fig. 11–2. The weather forecast districts and areas in Canada.

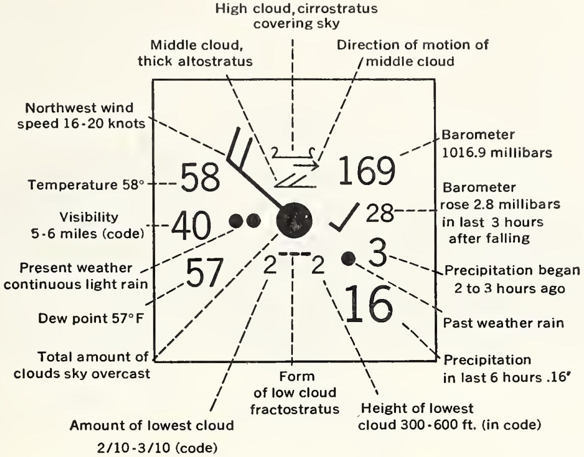

High cloud, cirrostratus covering sky
Middle cloud, thick altostratus
Direction of motion of middle cloud
Northwest wind speed 16-20 knots
Barometer 1016.9 millibars
Temperature 58°
Barometer rose 2.8 millibars in last 3 hours after falling
Visibility 5-6 miles (code)
Present weather continuous light rain
Precipitation began 2 to 3 hours ago
Dew point 57°F
Past weather rain
Total amount of clouds sky overcast
Precipitation in last 6 hours .16"
Form of low cloud fractostratus
Height of lowest cloud 300-600 ft. (in code)
Amount of lowest cloud 2/10-3/10 (code)
58
169
40
28
57
3
2
2
2
16

Fig. 11–3. Explanation of the complete station model used by the Canadian Meteorological Service.

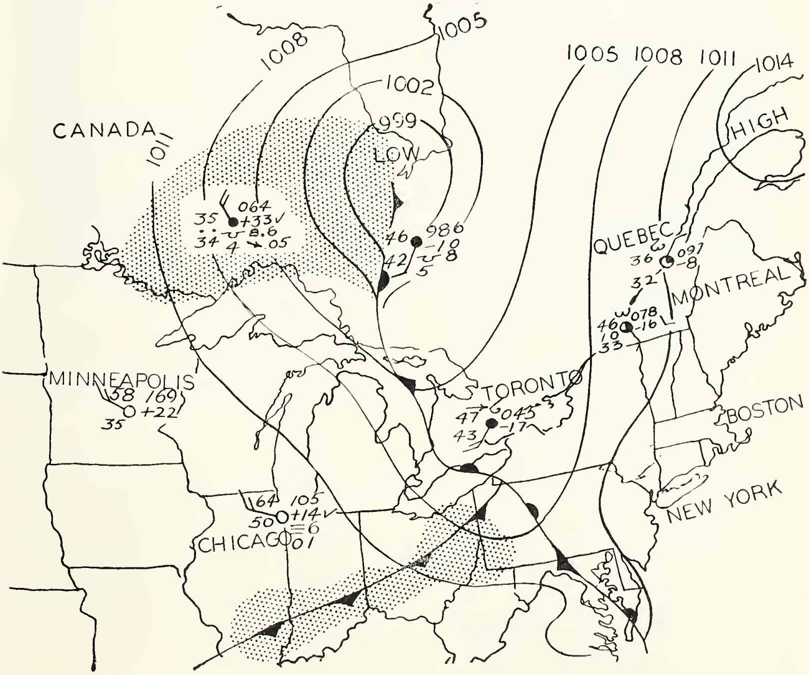
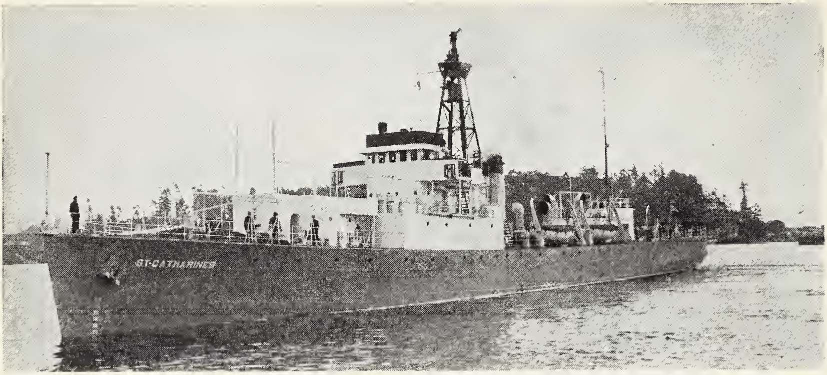


Fig. 11–4. Selected stations on part of a synoptic chart for May 6, 1952.



Doucette, Canada Dept. of Transport

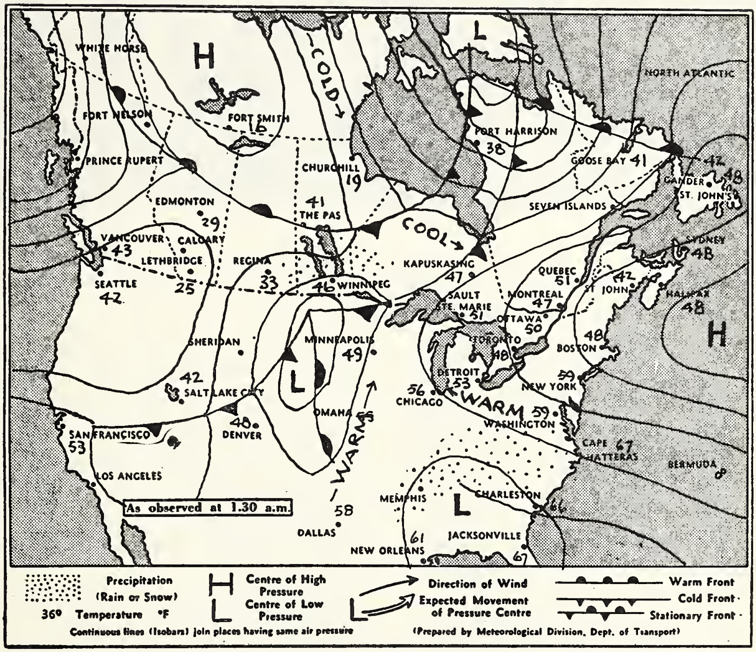
Fig. 11–5. The Canadian Weather Ship *St. Catherines.* Weather observations are made in the Pacific and Atlantic oceans by merchant vessels and special weather ships.

11–6 shows a simplified form of the daily weather map as it is published in some newspapers.

4. Weather forecasts and services. Before World War II there were only two weather forecast offices in Canada, the central office in Toronto, Ontario, and a smaller office in Victoria, B.C. They issued all the public forecasts for the whole country. After the war the country was divided into six Districts each with a single main forecast office for providing all the public weather services. These offices are located at Vancouver, Edmonton, Winnipeg, Toronto, Montreal and Halifax. A seventh District, Newfoundland, with an office at Gander, was opened after Newfoundland joined the confederation. Each district is in turn divided into a number of smaller areas for local forecasts. Forecasts are issued daily at six-hour intervals. Each of the regional forecasts describes the expected cloudiness, precipitation, winds and temperatures in the next 24 or 36 hours. An outlook for the third day is included previous to week-ends and holidays. Special warnings are issued when hazardous weather conditions, such as heavy snowfalls and freezing rain, are expected. The forecasts and warnings are available to the public through radio, television (on which a simplified synoptic chart is used), newspapers and by telephone from forecast offices. Long-range forecasts for 5 days or more are not at present available in Canada, although experimental forecasts of this type are being made.

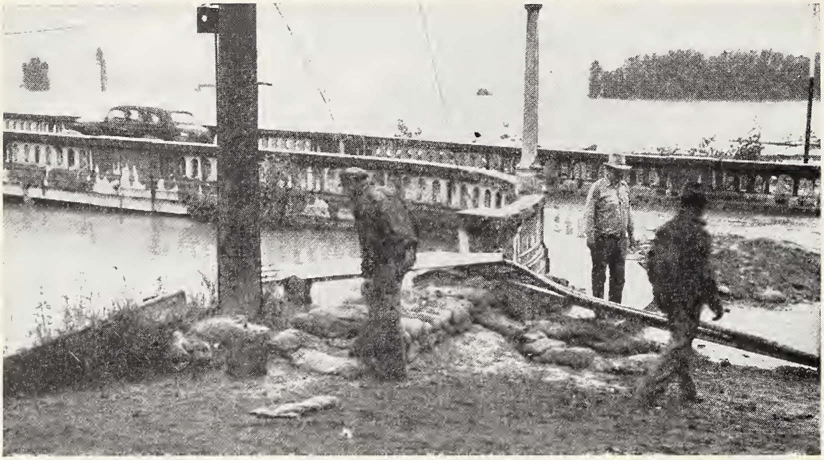
Aviation forecasts valid for 24 hours are issued daily at six-hour intervals by over 20 District Aviation Forecast Offices. Aviation forecasts are also available for Trans-Atlantic, Trans-Polar and Trans-Pacific flights. Other forecast services available from all or some of the weather offices include marine forecasts for shipping on the Atlantic, Pacific and Great Lakes waters; a daily service of recorded forecast temperatures for shippers of perishable commodities; forecasts in summer to forest fire prevention organizations; frost and harvest forecasts for farmers; and highway weather forecasts in winter.

5. The value of weather services. It is difficult to make an accurate evalua-



Courtesy The Montreal Star

Fig. 11–6. The modified form of weather map that appears in *The Montreal Star.*



Corps of Engineers, U.S. Army

Fig. 11–7. At the left, an observer of the River and Flood Forecasting Service of the Weather Bureau takes readings of the height of a flooding river at a river gauge station. The Kootenai River at Bonners Ferry, Idaho.

tion of the financial value of the work of the weather offices, but it unquestionably saves the country many millions of dollars annually, over and above the cost of its operation. Directly and indirectly, every single resident of the country benefits in comfort and convenience, as well as in dollars and cents, through the varied services provided by the Meteorological Service.

To the schoolboy and the man going to work, the daily weather forecast is a guide that tells him how warm to dress, whether or not to wear rubbers and raincoat or carry an umbrella. To the railroads, the freight steamship lines, and the truckers of perishables, the weather forecast is a guide to the taking of measures necessary to protect shipments of vegetables, fruits, eggs, meat, livestock, fish, and shellfish.

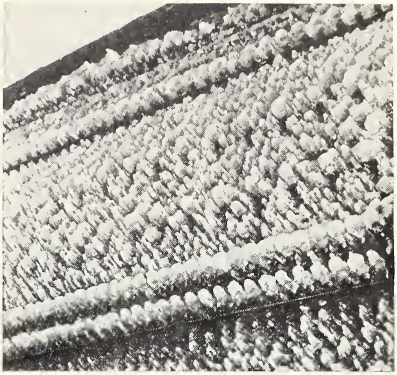
The forecast of a cold wave calls for action by gas and electric companies, fuel dealers, heating maintenance men, automobile owners, merchants, and welfare organizations, at the same time as it slows down or temporarily halts other activities as different as the mixing of concrete or the manufacture of ice cream. The forecast of a snowstorm calls for preparations by highway and railroad maintenance crews. Coastal storm warnings save millions of dollars' worth of shipping annually and prevent the loss of many lives.

Weather services enable farmers to save fruits, vegetables, tobacco, and young corn from frost. Hay, and alfalfa can be protected from spoilage by rain. Fruit orchards may be sprayed at the most advantageous times. Flood forecasts are instrumental in the protection of life and property, while forest fire-weather forecasts are invaluable in planning for the protection by forest services.

6. Weather and aviation. In these days of high-speed long-distance aviation, accurate weather information is imperative to safety. The weather service provides such information in regional and terminal forecasts issued from over 20 centers every 6 hours by teletype. The forecasts include height and thickness of clouds, general weather, presence of fog or dust, winds aloft, rough air, and icing conditions for all civil airways and for over 250 airports. Individual flight forecasts are also issued at most airport meteorological stations, and pilots in flight are advised by radio of sudden development of dangerous flying conditions. Landing weather reports and altimeter settings are radioed to airplanes approaching airfields for a landing.

There are several important hazards which a pilot must, if possible, avoid. *Icing conditions* may occur in flying through the freezing rains of warm and cold fronts, thunderstorms, and clouds on the windward sides of mountains. As in the formation of sheet ice or glaze on the ground, large raindrops freeze on airplane wings and propeller to form sheets of *glaze* or *clear* ice which seriously and often destructively interfere with flight. Smaller water drops may freeze to form a white granular deposit resembling frost and known as *rime ice* (rime means "frost"). Rime is easily broken off and is much less dangerous than glaze. Ice may also affect an airplane's controls, carburetor, instruments, and windshield visibility.

Thunderstorms with their powerful updrafts and downdrafts and their violently twisting squall winds are another hazard to be avoided in flight. Safe flying also requires good *visibility* and fairly high cloud *ceilings*, particularly near airports, and government regulations prohibit flight when visibility and ceiling are less than specified minimums. Airport *fogs* make safe landing and take-off well-nigh impossible, causing cancellation of all scheduled flights. Under such conditions, airplanes scheduled to land at an airport are directed to alternate airports where conditions are better. Every flight plan must include an alternate airport, and the plane must carry sufficient fuel to reach the alternate destination. Where radar equipment is available at airports, planes may be "talked down" in bad weather.



U.S. Army Air Force

Fig. 11–8. White, rough crystals of rime ice on the lower forward section of an airplane wing.

Knowledge of weather en route enables the working-out of a flight plan which may avoid dangerous icing conditions, storms, and strong headwinds, while knowledge of bad weather at the destination airport may make advisable the postponement of the flight or the selection of an alternate destination.

HAVE YOU LEARNED THESE?

Meanings of: weather map; glaze; rime
Explanations of: making of a weather map; the station model; flight dangers; weather services

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is a weather map. (*b*) Give a brief history of the development of weather maps and the Canadian Meteorological Service.

2. (*a*) What are the sources of weather observations used on weather maps? (*b*) Who makes the official forecasts? (*c*) What is the source of upper-air observations? (*d*) What is the facsimile, and how is it used in the weather service? (*e*) Why is the weather map called "synoptic"?

3. (*a*) What is a station model? (*b*) What advantage is there in the use by weather bureaus of international station-model forms and weather codes? (*c*) From Figures 11–4 and 11–5, read the weather information at your own locality and at nearby cities.

4. List the weather services provided by the Weather Bureau.

5. (*a*) Describe a few of the ways in which weather services are of value to the Canadian people. (*b*) What uses do you make of weather forecasts?

6. (*a*) What services does the Weather Bureau provide for aviation? (*b*) In what ways is ice formation a flying hazard? (*c*) What flight dangers are presented by thunderstorms? (*d*) What weather conditions complicate take-off and landing? (*e*) Distinguish between glaze and rime on airplane surfaces. (*f*) What is an alternate airport? (*g*) What is a flight plan?

GENERAL QUESTIONS

1. Why is it important to the forecaster that he should be able to compare the synoptic charts from earlier in the day when he is making an evening forecast?

2. What preparations are made, when a cold wave is forecast, by the groups referred to in Topic 5?

3. In what ways may provincial forest services plan for protection against forest fires, as mentioned in Topic 5?

4. Why should cold fronts usually present greater flight hazards than warm fronts?

5. Why are frontal thunderstorms greater flight hazards than air-mass thunderstorms?

6. At very high altitudes there is little danger of icing. Why?

STUDENT ACTIVITIES

1. Forming a school weather bureau which has its own instrument shelter, makes its own observations, and posts reports and forecasts on school bulletin boards, and so on. Get the Meteorological Service's "What you can do about the Weather" and other instruction and code pamphlets, write to the Meteorological Branch, Department of Transport, 315 Bloor Street West, Toronto, Ont., for a free price list of their publications

2. Learning the weather codes and symbols described on the reverse of the Canadian weather map

3. Reading the station models on weather maps

4. Plotting station models showing local observations

5. Visiting local and airport offices of the Canadian Meteorological Service

SUPPLEMENTARY TOPICS

1. History of the Canadian Meteorological Service

2. Types and Locations of Meteorological Stations

3. Special Weather Forecasts and other Services
4. Weather Forecasting Methods
5. Meteorological Service Codes and Symbols
6. Weather Hazards in Aviation
7. Flight Plans Through Fronts
8. Weather Factors in Insect Spraying
9. Instrument Flying
10. Airport Fog Prevention
11. Sequence Reports

SUGGESTIONS FOR FURTHER READING

Publications of the Canadian Meteorological Service including:

What you can do about the weather

Meet your weatherman

Weather map series

A guide to the weather map series

Making the most of the forecast

Storm, by George Stewart, Random House, New York, 1941.

(*Also see list at end of Chapter* 1.)

Chapter 12

LIGHT AND COLOR IN THE SKY

1. Seeing things. When light from any object comes to the eye, that object is "seen." If the light is produced by the object itself, as with the sun, a star, a gas flame, or a hot electric-light wire, the object is described as *self-luminous*. If the light is supplied by some other source, as when sunlight lights up the earth's surface, the planets, the moon, or the interior of a schoolroom, the objects thus seen are said to be *illuminated*. If the source of light is extinguished, or if something prevents the light from reaching the eye, the object cannot be seen. Two conditions, then, are necessary for seeing an object: it must give off light, and that light must reach the eye.

2. Apparent position. To be seen, an object need not send light rays directly to the eye, even though light does travel in straight lines. Objects that are behind us, for example, may be seen in a mirror. In this case, the light rays go from the object to the mirror, then from the mirror to the eye. A periscope enables a submarine observer to see over the ocean surface, and arrangements of mirrors enable drivers to see rear exit doors in crowded buses. But whenever we "see," the human eye places the object it sees *in the straight-line direction from which the last rays of light came*, and it is only familiarity with the mirror or periscope that teaches us to interpret the position of the viewed object correctly. Even after long experience a person watching the street through a barber-shop or restaurant mirror often becomes confused as to the real position of the objects he sees in the mirror.

3. Bending of light. When light rays pass from air into water or vice versa,

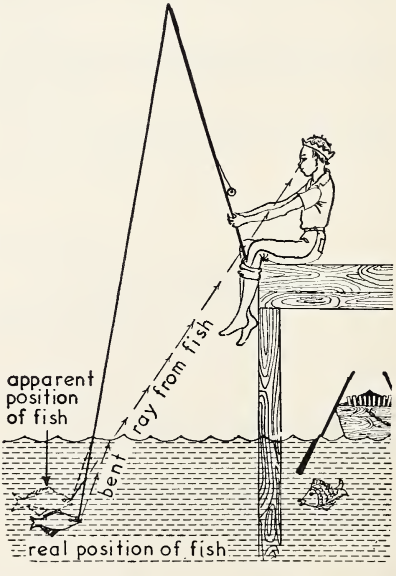


Fig. 12–1. Refraction of light causes the position of a fish in the water to appear higher than it really is.

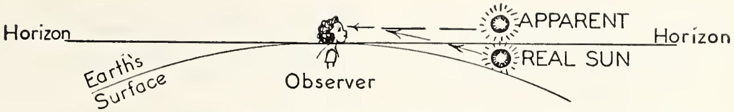


Fig. 12–2. Refraction lengthens the day at sunrise and sunset by causing the sun to appear above the horizon even when slightly below it.

they change direction and are said to be *bent*. This bending of rays of light in passing from one transparent material to another of different density is called *refraction*, and its effect is to change the apparent position of an object, since the eye sees the object in the direction of the rays of light that strike the eye. A familiar illustration of this effect is the apparent bending of a stick held partly in water. The eye sees the rays from the water part of the stick in a different line from those of the part in the air, and the stick appears to be broken.

4. Bending in the atmosphere. In the atmosphere light rays change direction when passing through air layers of different density. Normally, the layers of air nearest the ground are denser than the upper layers, although on very hot surfaces the lower layers may be less dense than those immediately above them. As a result of the bending that light rays undergo in these layers of air having different density, four very interesting effects of changed apparent position occur.

(*a*) *Sunrise and sunset.* For from 2 to 4 minutes (in middle latitudes) before the sun appears above the horizon, its light rays can be seen by an observer because they are bent downward toward the surface of the earth. Consequently the sun is "seen" before it actually rises. In the same way it is "seen" for the same length of time after it sets. The effect is the same for the moon (see Figure 12–2).

(*b*) *The sun's shape.* The closer to the horizon the greater is the bending of light rays. The result is that the lower portions of the sun and moon appear to be raised more than the upper portions, and their shapes look flattened when they are very low in the sky.

(*c*) *Twinkling of stars.* A star, many light-years distant from the earth, is but a pinpoint of light in the sky. Its light, too, is bent as it passes through the layers of the atmosphere. Any movement of these layers by the wind will change the amount of bending. This, in turn, changes the apparent position of the star at each moment, and makes the star seem to dance up and down in the sky,

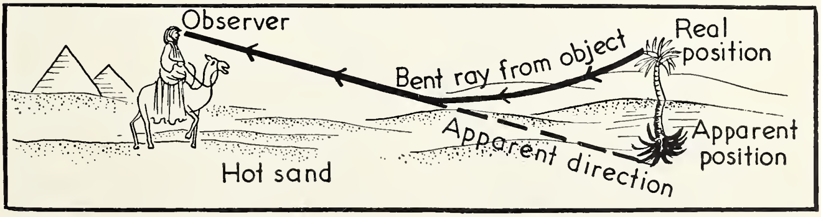


Fig. 12–3. The refraction of light rays over desert areas often causes distant objects to appear upside down as though reflected in a body of water. This optical illusion is called a mirage.

or "twinkle." The closer the star is to the horizon, the greater is the thickness of air through which its light passes, and the more it twinkles. Planets do not twinkle. Being much closer to the earth, they appear as sizable round disks which give off many rays of light at once, and the changes of position of individual rays are not conspicuous.

(*d*) *Mirages.* In the three illustrations just considered, the denser air layers were near the earth, and the effect of bending was to create an apparent position higher than the object's real one. In mirages, the reverse is true. In hot desert regions, or on hot concrete highways, the lower air layers may become so highly heated by contact with the hot surface as to become much less dense than the upper air layers. The light rays from distant high objects may bend upward from the lower hot air, and reach the observer's eye as if they came from below the surface (see Figure 12–3). A distant tree or building is then seen upside down as if by reflection, and the illusion of a body of water is created. On a concrete highway, such mirage effects make the road look wet.

5. Color. Just as an object's apparent position depends on the direction from which its light rays come, so its color depends on the color of the light it sends to the eye. Sunlight, or white light, is a mixture of light of different wave lengths, and each wave length is a different color. In passing through layers of different densities the shorter waves are bent more than the longer waves. Consequently, when sunlight passes through a thick triangular glass prism, the different wave lengths are separated sufficiently to produce a band of colors called the *spectrum*, ranging through red, orange, yellow, green, blue, and violet. The red, longest wave length, is bent least; the violet, shortest wave length, is bent most **(see Figure 12-4)**.

When white light strikes an object, the object will look white if it reflects all the wave lengths equally well. If it absorbs some of the wave lengths and reflects the rest, it will look colored. If it absorbs all the light and reflects none, it will look black. The apparent color of an object also depends on the color of the light that strikes it. For example, a white object, illuminated by red light or green light alone, can reflect only that color, and will look red or green. A red object reflects only red light, and absorbs every other light. If red light illuminates it, it will look red. If green light strikes it, the green is absorbed, nothing is reflected, and the red object looks black.

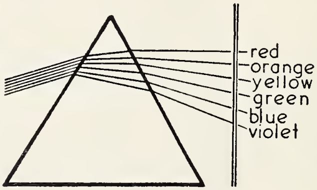


Fig. 12–4. This diagram shows how a glass prism breaks up a beam of white light into its component colors. The band of colors is the spectrum.

6. Color in the sky. (*a*) *The rainbow.* During "sun showers" one part of the sky is clear and the sun is visible, while in another part of the sky there are clouds and it is raining. If the sun and the rain are opposite each other, and the sun is low in the sky, an observer with his back to the sun may see a rainbow. The raindrops in the air act like prisms, splitting the sunlight that strikes them into the colors of the spectrum, and reflecting this light to the eye of the observer. Since the sun must be low in the sky, rainbows cannot be seen around midday. They are most frequent in late summer afternoons after thundershowers.

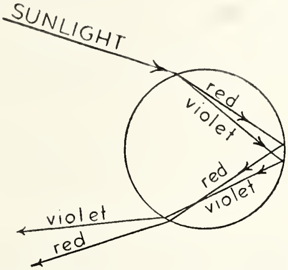


Fig. 12–5. Raindrops act like prisms and mirrors in forming the rainbow.

(*b*) *Halos.* Halos, or "rings," around the moon and sun are produced when rays of light pass through the ice crystals of thin cirrostratus clouds. Here the crystals act like prisms, splitting the light into colors and causing the observer to see a ring that is reddish on the inside and blue on the outside, as in the spectrum. The halo of the moon is fainter than the halo of the sun, and its colors are hardly noticeable. Cirrostratus clouds are usually part of an approaching warm front cloud system, so seeing a halo may mean that rain or snow will soon follow.

(*c*) *Blue sky and yellow sun.* The daytime sky looks blue because blue light is coming from it to the eye of the observer. This is because of "selective scattering." The atmosphere contains billions and billions of microscopically small dust particles which interfere with the passage of light rays. But these particles interfere more with the passage of the short violet, blue, and green waves than they do with the longer red, orange, and yellow waves. Looking toward the sun, an observer sees a yellow sun because much of the blue light has been screened out by the dust particles. The nearer the sun comes to the horizon and the more dust there is in the air, the redder the sun looks. Looking at the sky away from the sun, the observer's eye receives the blue waves which have been "scattered" out of the sun's white light, and the sky appears blue. High in the stratosphere, where there are no dust particles to scatter or reflect *any* of the sun's light to the eye, the sky looks black, and the stars can be seen in the daytime.

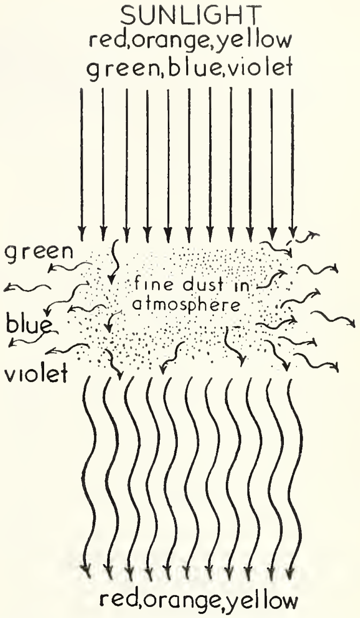


Fig. 12–6. Selective scattering of sunlight by dust makes the sky look blue and the sun look orange or yellow.

(*d*) *Cloud colors and sunsets.* As with other objects, the color of a cloud is that of the light which it sends to the eye. Clouds reflect all colors equally well. During most of the day ordinary sunlight strikes the clouds. Since the clouds reflect all of the wave lengths

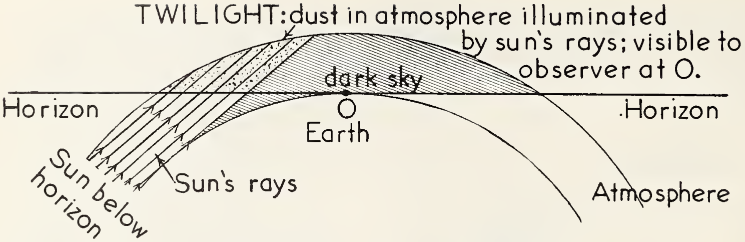

TWILIGHT: dust in atmosphere illuminated by sun's rays; visible to observer at O.
dark sky
Horizon
O
Earth
Horizon
Sun below horizon
Sun's rays
Atmosphere

Fig. 12–7. When the sun is a short distance below the horizon, as before sunrise or after sunset, it illuminates dust and clouds high in the atmosphere. This twilight, as it is called, can be seen by an observer at O.

equally well, they appear white. In early morning or late afternoon, however, the sun is close to the horizon and its light appears to be largely red or orange in color, as explained above. At such times the clouds reflect these colors, producing varying appearances, depending on their positions, composition, and shapes. At the same time, patches of green, blue, or violet sky may be seen through and around the clouds to produce the magnificent patterns so often seen at sunrise or sunset.

7. Twilight. Long after the sun has disappeared below the horizon and day has ended, daylight continues and only gradually fades away into night. This period of fading daylight is known as *twilight.* Similarly, in early morning before sunrise, twilight arrives to break the dark of night, gradually increasing its illumination until the sun appears over the horizon. These periods of evening *dusk* and morning *dawn* are the result of the reflection of sunlight from the dust and clouds in the atmosphere, as illustrated in Figure 12–7. From the duration of twilight, Arab astronomers thousands of years ago calculated the approximate height of the atmosphere.

HAVE YOU LEARNED THESE?

Meanings of: refraction; spectrum; self-luminous; illuminated

Explanations of: seeing the sun below the horizon; the sun's shape near the horizon; twinkling of stars; mirages; color; rainbows; halos; sky color; color of sunsets; twilight

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Explain what "seeing an object" consists of. (*b*) Distinguish between self-luminous and illuminated objects. Give examples.

2. (*a*) Give an illustration to prove that an object may be seen even though light rays do not go directly from it to the eye. (*b*) Where does the eye place the object it sees?

3. (*a*) What is the refraction of light? (*b*) What effect does refraction have on apparent position? Explain and illustrate.

4. (*a*) What causes light rays to bend in the atmosphere? Explain how the sun can be seen for a few minutes before it rises and after it sets. (*b*) Why does the sun look flattened when it is low in the sky? (*c*) Why do stars twinkle? Why do planets not twinkle? (*d*) Explain formation of a mirage. In what way is the formation of a mirage different from the other refraction effects of this topic?

5. (*a*) What is the spectrum? (*b*) What determines the color of an object that is illuminated by white light? (*c*) How can a white object look colored? (*d*) How can a colored object look black?

6. (*a*) What causes rainbows? Why are they commonest in late summer afternoons? (*b*) What causes halos? Why do they often mean that precipitation will soon occur? (*c*) Explain how selective scattering makes the sun look yellow, orange, or even red, while making the sky look blue. Why is the sky black at very high altitudes? (*d*) Explain how cloud colors may vary with time of day.

7. What is twilight? What causes it?

GENERAL QUESTIONS

1. Even planets may twinkle when near the horizon. Why?

2. Why does the sun look redder as it approaches the horizon, or when the air is very dusty?

3. Why are cold clear winter nights very poor nights for stargazing through telescopes?

4. Why are rainbows unlikely in winter?

5. Sunset colors can be seen in the eastern sky as well as in the west. Why?

6. Twilight lasts longer in high latitudes than in low latitudes. Why?

STUDENT ACTIVITIES

1. Observing the duration of twilight
2. Observing the sequence of sunset or sunrise colors
3. Observing the variations in sky color between the sun and the horizon
4. Observing the effect of haze on sky color
5. Forming and studying a spectrum, using glass prisms
6. Observing the arrangement of colors in halos and rainbows

SUPPLEMENTARY TOPICS

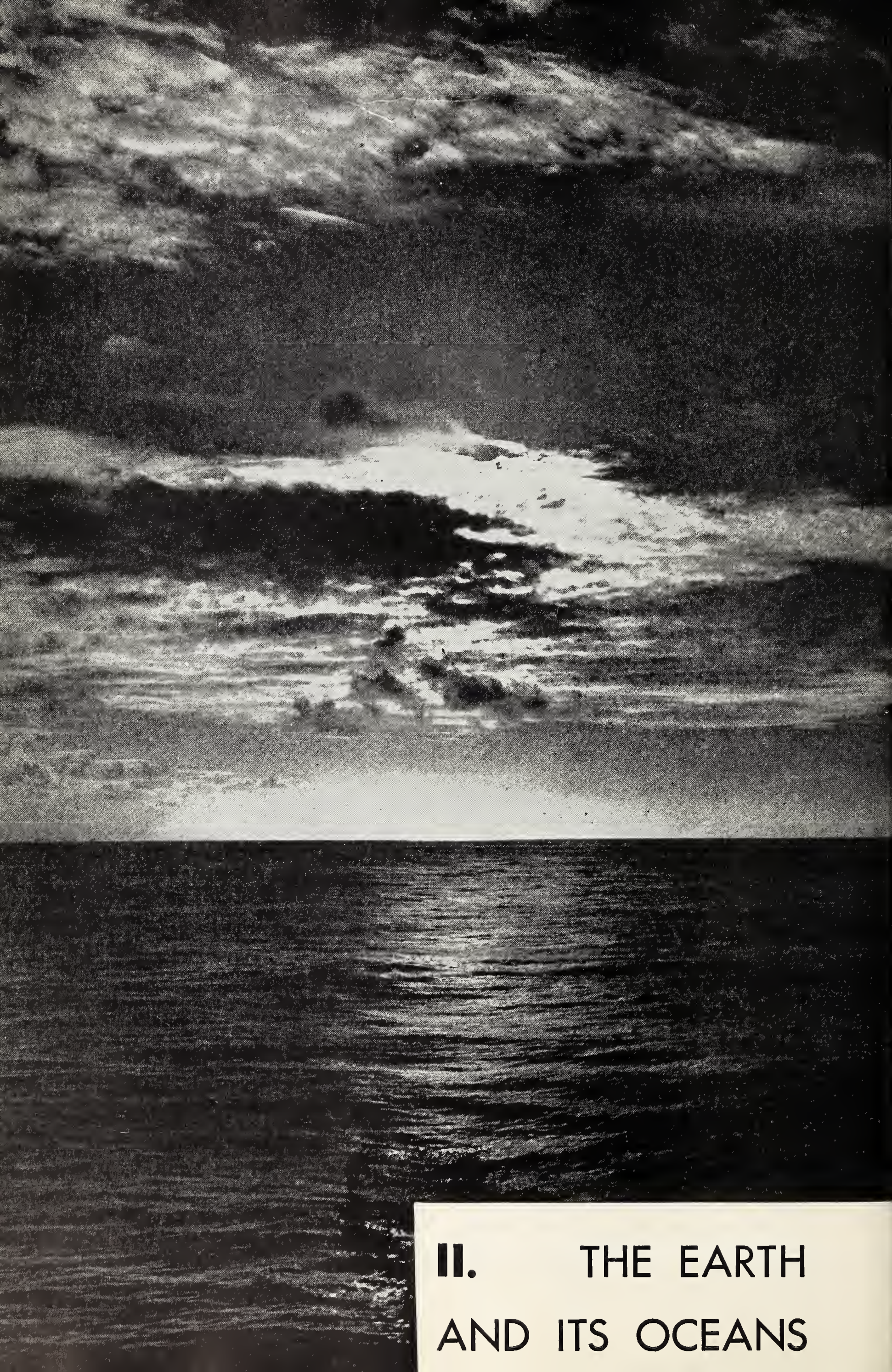
1. The Periscope
2. Mirages and Looming
3. Primary and Secondary Rainbows
4. Coronas, Halos, and Sun Dogs
5. The Duration of Twilight
6. Measuring the Height of the Atmosphere from the Duration of Twilight
7. Sky Color in the Stratosphere
8. Atmospheric Haze

SUGGESTIONS FOR FURTHER READING

Physics of the Air, by W. J. Humphreys. McGraw-Hill, New York, 1940.

Meteorology, by W. I. Milham. Macmillan, New York, 1936.

(*Also see list at the end of Chapter 1.*)



II. THE EARTH AND ITS OCEANS

There was a time, not so many years ago, when the oceans were known as the "highways of the earth." Today, as a result of the invention of the airplane, the oceans must share this title with the atmosphere. But man has not freed himself completely of the oceans, and it is hardly likely that he ever will. Covering nearly three times as much of the earth's surface as does the land, the oceans are of prime importance in their effects on world climates. And whether man sails his ships over the surface of the oceans or flies his airplanes above them, the weather on the ocean must always be reckoned with. But man does not wish to make himself independent of the oceans. On the contrary, he seeks to make more and more use of the vast resources of their waters, and to extend his mastery of the oceans far into their depths. For from the ocean come essential foods, valuable fats and oils, and valuable minerals. Even more, the scientist seeks in the ocean the answers to many of the fundamental secrets of the earth. The science of *oceanography* is today one of the most active of all branches of science.

The activities of the oceanographer are highly varied. He uses sound waves that go down to the bottom of the ocean and return to give him information about the depth and the contour of the ocean's floor. He uses strange scoops and drills to obtain samples of the sediments that lie thousands of feet down on the ocean bottoms. He fires charges of explosives below the surface of the sea so that he may learn how thick are the sediments that cover the bedrock of the ocean basins. In odd-shaped vessels he risks his life within the inky blackness of deep ocean waters so that he may see with his own eyes the weird creatures that live in a world of perpetual cold and darkness.

He goes in specially equipped ships on prolonged expeditions, sometimes lasting for years, to obtain information about the currents of the ocean surface and the more mysterious movements of the deep sea. He allows his ship to be frozen into the polar sea in order that he may drift with the ice floes into areas not accessible in any other way. He may seek to verify or disprove the legend of a Sargasso Sea or of a lost continent of Atlantis or to explain the origin of mighty canyons that cut deep into the shallow shelves which extend seaward from the continents.

The chapter that follows is but a brief introduction to this wonderful study of oceanography. If it catches your fancy at all, be sure to follow it up by reading one of the books listed at the end of the chapter.

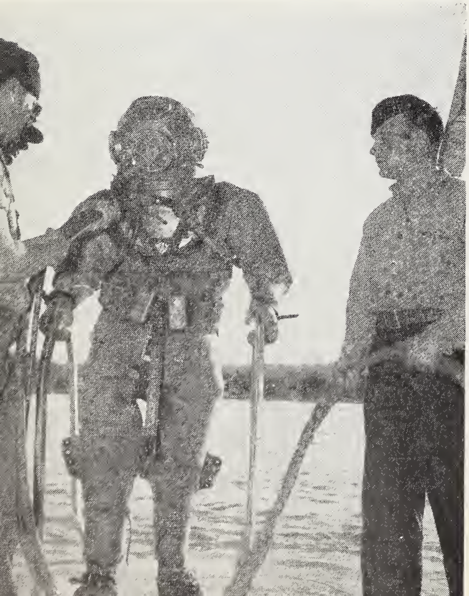
Chapter 13

THE OCEAN AND ITS CURRENTS

1. How much ocean? The oceans cover almost three-fourths of the earth's surface. They are continuous; that is, it is possible to sail from any one ocean into all the other oceans—but geographers recognize five great divisions. Of these, the Pacific Ocean is by far the largest, followed by the Atlantic, the Indian, the Antarctic, and the Arctic. Not only do the oceans cover 2½ times as much area as the lands, but they are also much deeper than the lands are high. The average depth of the oceans is about 2½ miles, while the average height of the land is about ½ mile. The ocean's deepest area, in the Pacific Ocean east of the Philippine Islands, is almost 7 miles deep, while the earth's highest mountain peak, Mount Everest, is less than 6 miles high.

Fig. 13–1. Navy diver ready for a deep sea dive. His equipment weighs approximately 190 pounds, distributed as follows: helmet, 54 pounds; shoes, 35 pounds; lead-weighted belt, 83 pounds; rubberized waterproof suit, 18 pounds.

Official U.S. Navy Photo



2. Sounding the depths. The depth of any part of the ocean is found by *sounding*. Until recently, sounding meant measuring out a weighted line into the ocean until it touched bottom. In very deep water one sounding would take hours. Nowadays the *fathometer* measures ocean depths in seconds. (A fathom is a nautical measure equal to 6 feet.) The fathometer uses sound waves that travel through sea water at the rate of about 4800 feet per second. If the sound sent to the sea bottom is echoed back in 2 seconds, it means that the sound is taking 1 second to go down and 1 second to return; the water is therefore 4800 feet deep.

The sounding line has become obsolete as a measure of depth, but it is still used when temperatures at various depths are desired, or when samples of deep-sea water and sediments must be obtained. For these purposes special thermometers, self-closing bottles, scoops, and other instruments are attached to the line. A recently invented device can drill to depths of 70 feet in the deep sea floor, bringing to the surface long slender *cores* of ocean sediments.

The greatest depth reached by living man is 13,284 feet, a record achieved by two French naval officers in their bathyscaphe (*bath* ih skafe) when they reached the floor of the Atlantic Ocean 120 miles west of Dakar, Africa, early in 1954. This record will undoubtedly be surpassed as new expeditions are organized and new equipment developed.

3. The shape of the ocean floor. If all the waters of the ocean were removed from the earth's surface, the ocean floor would be exposed as a smoothly rolling surface with slopes generally more gentle than almost any part of the continents. The smoothness of the ocean floor is explained by two facts: (1) no erosion takes place in the quiet waters far below the surface; (2) sediment of many kinds is always being deposited in the ocean, helping to fill in the irregularities of its floor.

On the basis of depth, the ocean floor may be divided into five sections. The *continental shelves* slope gently outward from the shores of the continents until they reach the steep *continental slopes.* The average depth at the end of the shelves is about 400 feet, although this varies a good deal. The shelves are usually very level, their slopes averaging only a few feet per mile, so they may extend several hundred miles from the continents. On some continental shores, however, shelves are very narrow or almost absent. On both the American and European sides of the North Atlantic Ocean the shelves are large (see Figure 13–2).

At the outer edges of the continental shelves the slope of the sea floor increases to between 50 and 100 feet per mile—much more than the slope of the shelves, but still very gentle in comparison with mountain areas on hand. This steeper slope is called the *continental slope.* It continues to an average depth of about 12,000 feet, though it may go as deep as 30,000 feet. Where the slope ends the ocean bottom becomes gentler again, and for thousands of miles the deep ocean floor rolls irregularly along in ups and downs that form the major part of the *ocean basin.*

Here and there the floor rises high into great *plateaus* that may come within a few thousand feet of the ocean surface. In other areas the floor may plunge sharply into great abysses, known as *ocean deeps* if they reach below 20,000 feet. Most ocean deeps occur close to great mountainous islands from whose steep shores the continental slope plunges sharply down to the bottom of

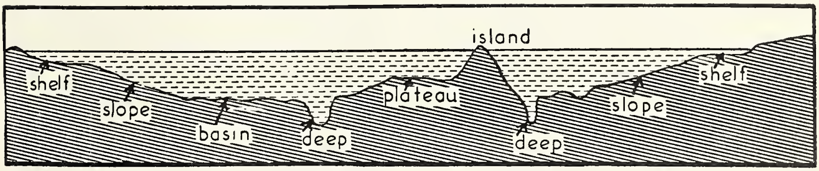


Fig. 13–2. A profile of the ocean floor. Vertical scale greatly exaggerated.

the sea (see Figure 13–2). Greatest of all the deeps is the Mindanao Deep east of the Philippine Islands, with a record depth reported to be 35,400 feet. Other great Pacific deeps lie east of Japan, east of New Zealand, and near the island of Guam. The greatest deep in the Atlantic Ocean is the Nares Deep north of Puerto Rico. It is nearly 28,000 feet deep.

In summary, it may be said that the continental shelves are, on the average, from 0 to 400 feet deep; the continental slope, ocean basin, and ocean plateaus are in waters about 400 feet to 20,000 feet deep; the ocean deeps are over 20,000 feet deep.

4. What is on the ocean floor? The type of deposit found on the ocean floor is determined largely by the depth and distance of the floor from the land. On the continental shelves are found gravels, sands, clays, and shell deposits. Beyond the continental shelves, wherever the depth is less than 15,000 feet, the floor is covered with soft, fine *oozes*, or muds, composed largely of microscopic shells of dead sea organisms, but including also bits of volcanic dust and meteorite dust.

At depths greater than 15,000 feet the ocean floor is covered with a fine red clay consisting almost entirely of volcanic and meteorite dust whose rusted iron is responsible for the red color. The absence of shells is explained by the fact that at these depths the sea water contains so much carbon dioxide gas that it is able to dissolve most of the shell minerals. The red clay accumulates at an almost incredibly slow rate, as is shown by the fact that nearly every handful of this material contains as much meteoritic iron as is found in thousands of tons of mantle rock on the land.

5. What minerals does sea water contain? Through millions of years of earth history, the rivers of the earth have been carrying both rock fragments and dissolved minerals down to the sea. The rock fragments settle on the continental shelves, to be returned to the lands some day in the form of the sedimentary rocks of a marine plain. Dissolved minerals do not settle to the bottom, however, nor does evaporation from the ocean surface remove anything but water. As a result, the dissolved minerals have accumulated, and today every 100 pounds of sea water contains 3½ pounds (3½ per cent) of invisible mineral matter. The percentage would be much higher were it not for the fact that lime and silica, the two commonest dissolved mineral substances in river water, are removed from sea water by shell-forming animals. The minerals that remain are those that are not extracted by the animals of the sea.

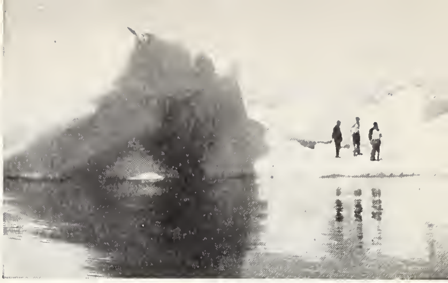
About three-fourths of "sea salt" is common sodium chloride or table salt, while the remainder consists largely of magnesium chloride, magnesium sulfate or Epsom salt, calcium sulfate, and potassium sulfate. Compounds of uranium, gold, silver, lead, and many other valuable metals are present in very small percentages in sea water, and sea water is already being used as a commercial source of bromine, iodine, and magnesium.

6. Ocean temperatures. At the surface, ocean water ranges in temperature from about 80° F at the Equator to about 27° F, its freezing point, in the polar regions. (Salt water does not freeze at 32° F, as fresh water does.) In general, temperatures decrease toward the Poles, but exceptions occur where warm or cold ocean currents are crossed. The daily range and annual range of ocean temperatures are much smaller than those of the land.

The sun's rays are the principal source of ocean heat, and they do not penetrate very far. Consequently we find that ocean temperatures decrease rapidly with depth. At 4000 feet, even in equatorial regions, the temperature is about 40° F or less; below 10,000 feet the temperature is usually 35° F or less. In polar regions the temperatures are close to freezing from top to bottom.

Apparently the low temperatures of the bottom waters of the deep ocean are maintained by a slow movement of cold water from the polar regions to the Equator along the ocean floor. This movement is referred to as *polar creep*. Proof of this is seen in the fact that where the ocean floor is high enough to keep out polar creep, as at the entrance to the Mediterranean Sea, the bottom temperatures may be as high as 55° F, even at a depth of 14,000 feet.

7. Pack ice and icebergs. The two main types of ice found in the sea are *pack ice* and *icebergs*. During the winter the surface of the Arctic Ocean freezes to a depth of 7 or 8 feet. There may be occasional cracks or *leads* in this ice, but it is usually easy to travel by dog team over it. During the short summer the pack ice breaks up and melts around the shores of the Arctic Ocean. On the Atlantic side ocean currents carry the ice south along the coasts of eastern Canada and Greenland. North of the Canadian Arctic Islands the pack ice never melts completely and no ship has ever penetrated into this part where the ice is very rough (hummocky) and may be 10 or 15 feet thick. In this area there are also a few ice islands. These may cover more than a hundred square miles and be over 150 feet thick. They drift slowly through the pack ice.



Official U.S. Coast and Geodetic Survey Photo

Fig. 13–3. A large iceberg, Glacier Bay, Alaska.

Icebergs are gigantic blocks of ice that break off glaciers if they end in the sea. Almost all the icebergs in the Northern Hemisphere come from the Greenland glaciers and are carried by ocean currents into the North Atlantic Ocean off Labrador and Newfoundland. During the summer they are a serious danger to shipping forcing it to travel southerly routes. Ever since 1912 when the steamship *Titanic* was wrecked on an iceberg off Newfoundland, the U.S. Coast Guard has maintained an International Ice Patrol which charts icebergs, broadcasts their position and blows up the smaller ones.

The largest icebergs in the north are ½ to 1 mile in length and may show 300 feet of ice above the water. As there is often eight times as much ice below the water, as there is above, the total height of the icebergs sometimes reaches 2700 feet. The greatest of all icebergs are those that break off the antarctic glaciers. Some of these tabular icebergs are over 40 miles long.

During the winter all the seas of northern Canada (including Hudson Bay) are covered with pack ice. This ice begins to break up in late June but shipping can not normally start until the end of July. It goes on until October when the new ice brings it to a halt.

8. Ocean currents. If the Equator is regarded as dividing the Atlantic, Pacific, and Indian Oceans into northern and southern halves, we find that each of these "oceans" has a circulation of surface waters moving around its margins. In the Northern Hemisphere this movement around the "ocean" is in a clockwise direction; in the Southern Hemisphere it is counterclockwise. The moving water is usually called a *drift* when it is broad, shallow, and slow-moving. Drifts are generally hundreds of miles wide and less than a hundred feet deep; their speed ranges from ½ mile to 2 miles per hour.

When the moving water is concentrated into a narrower, deeper, and more rapidly moving mass it is called a *current* or a *stream*. The Gulf Stream, most famous of all ocean currents, is best developed where it passes between Florida and Cuba. Here it is less than 100 miles wide, almost 2000 feet deep, and has a speed of from 4 to 5 miles per hour.

9. Origin of ocean currents. The currents of the northern Indian Ocean change their direction in winter and summer, showing plainly that they are caused by the monsoon winds of that region. In fact, all the ocean circulations appear to be caused by the steady blowing of the two great sets of winds in each hemisphere, the trades and the westerlies.

On both sides of the Equator *the trade winds cause movement of the surface waters* westward and toward the Equator. *The earth's rotation causes a deflection of these movements* to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The net result is that the waters move almost due west, parallel to the Equator, in both hemispheres. On the north side of the Equator these currents are called *North Equatorial Drifts;* on the south side they are *South Equatorial Drifts.* In general, these drifts continue westward until they reach continents or large islands. Then they swing away from the Equator in both hemispheres, move eastward across the oceans with the help of the prevailing westerly winds, and complete their circulations by re

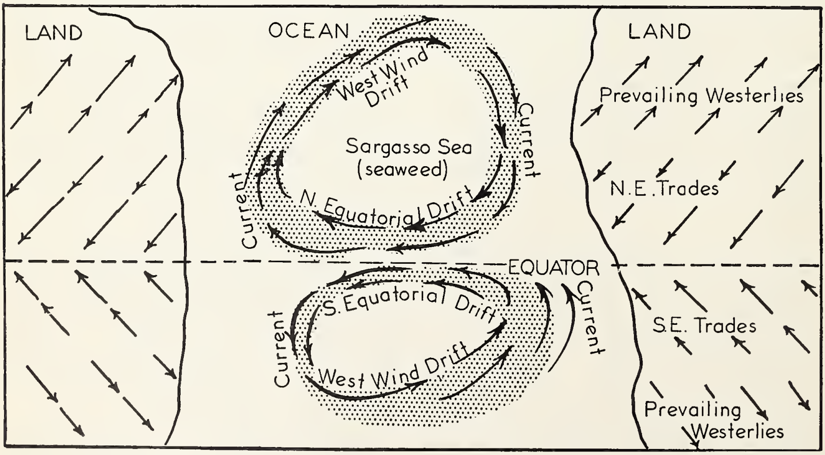


Fig. 13–4. General scheme of an ocean current system. (Prevailing winds blow over the oceans as well as the lands, but have been omitted to avoid crowding the diagram.)

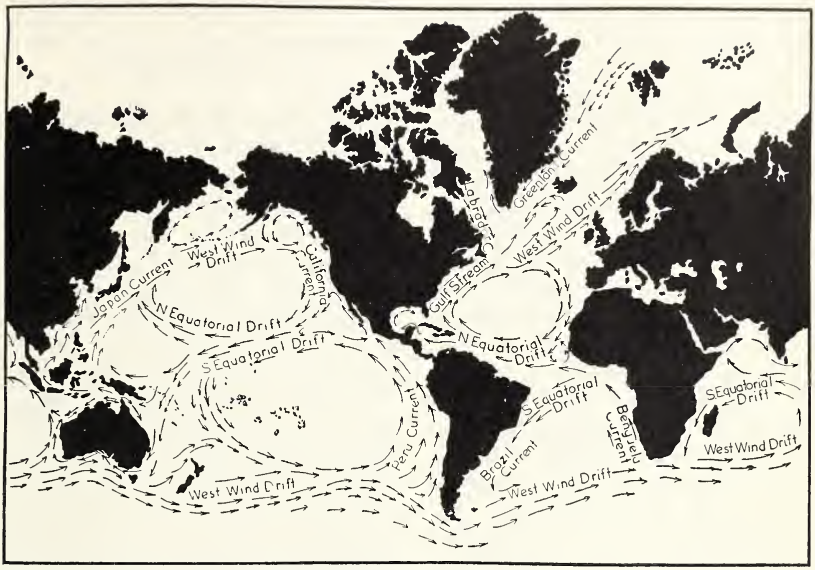


Fig. 13–5. Map of ocean currents of the world.

turning to the Equator at the eastern ends of the oceans. Movement along the shores of the continents appears to concentrate the drifts into currents.

Continuous deflection to the right in the Northern Hemisphere produces a clockwise circulation; deflection to the left in the Southern Hemisphere produces a counterclockwise circulation. As the currents move into the latitudes of the prevailing westerlies, they become broader and slower and are generally known as *West Wind Drifts.* Factors that influence the width, depth, and direction of currents, besides wind and the earth's rotation, are the depth and shape of the ocean floor and the outlines of the continents which they encounter. Currents that flow away from the Equator are warm currents; currents that flow toward the Equator are cold currents.

10. The Atlantic Ocean circulation. In the Atlantic Ocean the *South Equatorial Drift* flows west until it meets the projecting coast of Brazil. This splits it into two branches. The southern branch follows Brazil southward as the Brazil Current, moves across the ocean as a West Wind Drift, and then returns northward along Africa's west coast as the Benguela Current. The northern branch crosses the Equator to join and strengthen the North Equatorial Drift.

The *North Equatorial Drift* also flows westward until it comes to the West Indies, where it divides into two branches. One branch flows northward. The other branch continues westward into and around the Gulf of Mexico, from which, warmed and enlarged, it emerges through the Straits of Florida as the *Gulf Stream.* The Gulf Stream follows the coastline of the United States out past Cape Hatteras, where it rejoins the northern branch. Together they bend eastward at about 40° N latitude and move toward Europe as a West Wind Drift. Important branches fan out along the shores of Iceland, the British Isles, and Scandinavia, giving those regions climates far warmer than normal for their latitudes. Another branch turns southward as the *Canary Current* (passing the Canary Islands) to complete the circulation. The complete circulation of any ocean is often called an *eddy*. Inside the *North Atlantic Eddy*, away from currents and in the calm air of the horse latitudes, great masses of floating seaweed accumulate to form the *Sargasso Sea* (see Figures 13–4, 13–5).

The *Labrador Current* is a cold current that comes down from the arctic seas into the North Atlantic. Following the east coast of Baffin Island, it brings with it icebergs, pack ice and icy waters, chilling the coasts of Labrador, Newfoundland, and New England as far south as Cape Cod. Beyond this point its cold waters sink below the surface. The fogs of Newfoundland are caused by the Labrador Current's cooling effect on the warm moist air blown over it from the Gulf Stream.

11. The North Pacific circulation. In the Pacific Ocean, the *North Equatorial Drift* flows west until it meets the Philippine Islands, the East Indies, and the mainland of southeast Asia. From here a warm current emerges between the Philippines and Formosa. Swinging northeast as the *Japan Current*, it crosses the ocean as a West Wind Drift. This divides into a north-flowing *Alaska Current* which warms the southern coast of Alaska, and a south-flowing *California Current* which follows the coast of Washington, Oregon, and northern California to complete the *North Pacific Eddy*. The California Current, at least in summer, is generally cooler than the shores past which it flows.

HAVE YOU LEARNED THESE?

Descriptions of: the ocean floor and its deposits, ocean temperatures, floe ice, icebergs, Gulf Stream, Labrador Current, California Current

Explanations of: sounding, the fathometer, the development of ocean currents, the minerals in sea water, polar creep, Sargasso Sea

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Describe the extent and depth of the oceans as compared with the land.

2. (*a*) Compare the old and the new methods of measuring ocean depths. (*b*) What uses does the sounding line still have?

3. (*a*) How is the smoothness of the ocean floor explained? (*b*) Give a brief description of the five divisions of the ocean floor.

4. (*a*) Describe the 3 types of deposits found on the ocean floor. (*b*) Why does red clay contain hardly any shells? (*c*) How is the slowness of the formation of red clay shown?

5. (*a*) What is the origin of the dissolved minerals in the ocean? (*b*) Why does sea water contain more common salt than lime in solution?

6. (*a*) Describe the variations of ocean temperatures along the surface and from top to bottom. (*b*) What is polar creep?

7. Compare pack ice and icebergs as to origin, composition, and size. Describe the work of the International Ice Patrol.

8. (*a*) What are ocean drifts or currents? (*b*) In what directions do these currents circulate?

9. Describe the origin of the clockwise ocean currents of the Northern Hemisphere and of the counterclockwise currents of the Southern Hemisphere.

10. (*a*) Describe the general circulation of the Atlantic Ocean. (*b*) What is the

Sargasso Sea? (*c*) Describe the Labrador Current.

11. Describe the North Pacific circulation.

GENERAL QUESTIONS

1. How long does the fathometer take to measure the ocean's greatest depth?

2. What is the source of the deposits on the continental shelves?

3. Why does red clay accumulate more slowly than ooze?

4. Whale bones are frequently found in small quantities of red clay brought up from ocean deeps. Of what significance is this?

5. Why is deep sea water able to hold more carbon dioxide gas than surface water?

6. What factors cause the freezing point of sea water to vary from 27° F to 29° F?

7. Sealed bottles are used to study the drift of ocean waters. Why are these bottles weighted so that they barely float?

8. In what way does the earth's rotation help to keep the Labrador Current close to the shores of North America?

9. The Pacific Ocean is relatively warm off northern British Columbia, and cool off California. Why?

10. Is the ocean becoming more salty or less salty? Explain.

11. In the Southern Hemisphere the West Wind Drift goes completely around the world. Why?

STUDENT ACTIVITIES

1. Plotting a profile of the ocean floor
2. Constructing a model of the ocean floor
3. Constructing a large profile of the ocean floor *drawn to scale*
4. Determining the percentage of mineral matter in sea water
5. Analyzing the minerals in sea water

SUPPLEMENTARY TOPICS

1. Deep-Sea Explorations
2. The Fathometer
3. Deep-Sea Life
4. The Sargasso Sea
5. How Sea Water Freezes
6. The Movement of Icebergs and Pack Ice
7. Arctic Explorations
8. Oceanographic Expeditions
9. The Location of Ocean Deeps

SUGGESTIONS FOR FURTHER READING

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Mysterious Sea, by F. C. Lane. Doubleday, New York, 1947.

The Sea, by H. A. Marmer. D. Appleton-Century, New York, 1930.

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National Geographic Magazine.

III. THE EARTH AND ITS CLIMATES

Climatology is the study of climates and the factors on which they depend. Weather and climate are often distinguished by saying that weather is the state of the atmosphere at a particular time, while climate is average weather. But weather averages alone may fall as short of describing the climate of a region as the final score of a ball game may fail to give the whole story of the contest. For the ball game, an inning-by-inning score with a description of highlights gives a better picture of the kind of game that was played than could be supplied by either totals or averages alone. In the same way the climate of a region can be described far better by a season-by-season description of its weather with an account of highlights and outstanding features, than it could be by averages alone. To illustrate: Peiping, China and Valdivia, Chile have almost identical yearly average temperatures of 53° F, which might lead one to believe that their climates were very much alike. Far from it! A year in Peiping includes an icy January averaging 24° F and a broiling July averaging 79° F, as compared with Valdivia's mild 46° F and 62° F averages for its coldest and warmest months. In Peiping the annual range in temperature is therefore 55 degrees F; in Valdivia it is only 16 degrees F. Certainly their climates are not the same, yet their yearly averages would give such an impression. Similar contrasts exist in Canada between cities in the east and those on the west coast, such as Montreal and Victoria, in this case, however, the annual temperature of Victoria is about six degrees higher than Montreal.

(The term *temperature range* was defined earlier, but it bears repetition here. The *daily temperature range* is the difference between the highest and lowest temperatures of the day. The *yearly temperature range* is the difference between the averages of the warmest and coldest months of the year.)

Another important respect in which climates differ is moisture. Here, too, it is not enough to say, for example, what the yearly total of rainfall may be, for that would omit such vital information as when it falls, how much falls at one time, how often the skies are cloudy, and so on.

Bombay, India has a yearly rainfall of about 74 inches; in St. John, New Brunswick the yearly precipitation is about 40 inches. But almost all of Bombay's rain falls "in cloudbursts" during four summer months, and the rest of the year is practically rainless. In St. John the precipitation is so evenly distributed throughout the year, that on the average, in no month is it less than 3 inches.

Temperature and moisture are the most important weather elements to be considered in describing the climate of a region, but other elements often included are the prevailing winds, the time and number of frosts, the occurrence of storms, and the amount of snowfall. Climatology takes into account the variations of the weather elements as well as their averages, and its studies are based on the records of many years. The two chapters that follow will take up the factors that determine the climate of a region, and then briefly describe the principal climatic regions of the world.

Chapter 14

THE FACTORS THAT CONTROL CLIMATE

In analyzing the reasons for the existence of different climates, the climatologist or "climate scientist" has drawn up a list of factors which he calls *climatic controls*. Let us see how these factors control the year-round temperature and rainfall of the various parts of the earth's surface.

FACTORS THAT CONTROL TEMPERATURE

1. How latitude controls temperature. The latitude of a place—its distance from the Equator—has more to do with its temperature characteristics than any other single factor. Latitude helps to determine not only the average yearly temperature of a place, but also its daily and yearly ranges of temperature. Let us take a few illustrations.

Suppose you live within 5 degrees or 10 degrees of the Equator—perhaps in Panama or the Congo or northern Brazil. Every day of the year the sun shines for about 12 hours; every night is about 12 hours long. At noontime the sun is never very far from vertical, whether the month be July or January. Your climate is uniformly hot throughout the year, and your average temperature is very high—perhaps about 80° F. There is no summer and no winter—there are only rainy seasons and dry seasons—and your yearly range of temperature is but 3 or 4 degrees. Afternoons are, of course, very hot. Surprisingly, though, the rather long 12-hour nights may become cool by contrast, and the daily temperature range is fairly large. Climatologists even speak of the nighttime as "the winter of the tropics."

Now move to a middle latitude—40 degrees or 45 degrees from the Equator and almost halfway to the North Pole—perhaps to Chicago or Vancouver or Montreal. In July you enjoy 15 or 16 hours of strong sunshine daily, and nights are only 8 or 9 hours long. But six months later a weak sun shines only 8 or 9 hours a day, and for 15 or 16 hours each night your city radiates its heat off into space. On the average, your yearly temperature is far lower than that of the equatorial latitudes. The annual range of temperature is very large, perhaps as much as 50 degrees. Your daily temperature range is very variable but, all in all, perhaps not as large as in low latitudes.

Now move to the polar regions—to

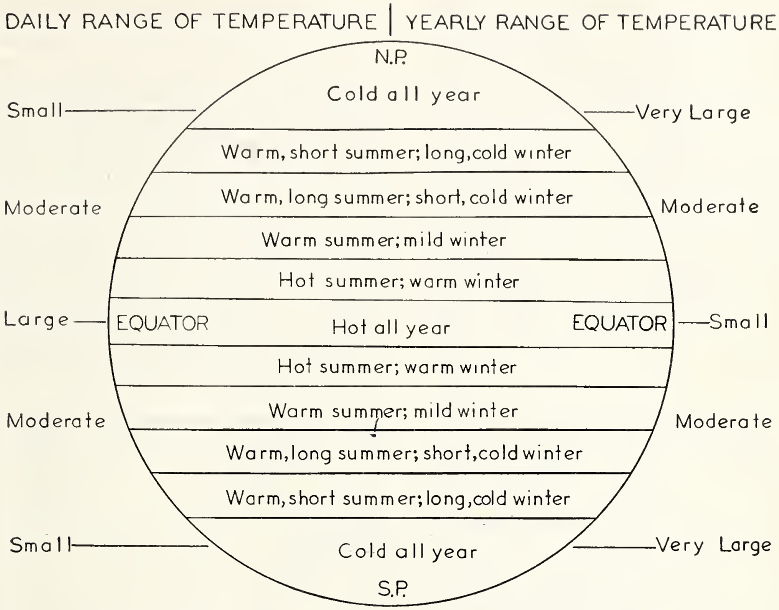

Fig. 14–1. The manner in which latitude alone controls temperature throughout the earth is shown in this diagram.

Baffin Island or Alaska or Antarctica. Here most of your sunshine comes in a "day" that lasts for many months. Your winter includes an equally long night. The weak sun is never high in the sky, but as it goes completely around the sky each day it stays at nearly the same height all day, and temperatures hardly change for days at a time. The summer is comparatively mild, but the long winter night becomes fearfully cold. In these high latitudes, then, the average annual temperature is very low, the annual temperature range is very large, but the daily temperature range is very small.

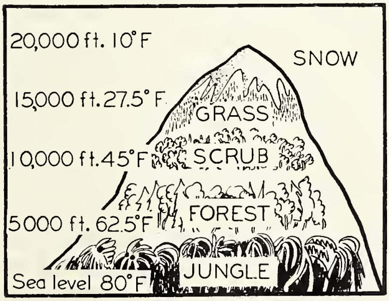

Fig. 14–2. The effect of altitude on temperature and vegetation at the Equator.

Figure 14–1 summarizes the connection between latitude and temperature. Most important is the principle that *the higher the latitude the colder the climate is likely to be.*

2. Altitude and temperature. *Altitude* is height above sea level. Its effect on temperature is similar to that of latitude. Increased altitude means lower temperatures at the average rate of 3½ degrees F per 1000 feet. *The higher the altitude the lower the average yearly temperature.* Mexico City, in the tropics but almost 7500 feet above sea level, has a cool pleasant climate that is in delightful contrast to the steaming atmosphere of Vera Cruz, at the same latitude but located at sea level. At still higher altitudes, even at the Equator, temperatures can be so low that snow always covers the mountain tops, and glaciers are formed. Mount Chimborazo, more than 20,000 feet high in the Andes Mountains of Ecuador, is only one of many mountain peaks located almost on the Equator, yet in a land of perpetual frost.

3. Land, sea, and temperature. Since land gains and loses heat much more quickly than water, land areas tend to have hot summers and cold winters, while sea areas have cooler summers and milder winters. Small islands have climates like those of their surrounding waters, these climates being known as *equable marine climates* (*equable* means "even" or "uniform"). The interiors of continents, on the other hand, experience greater extremes of temperature, especially in middle latitudes, and are said to have extreme or *continental climates*. Reykjavik, Iceland, 64° N, and Verkhoyansk, Siberia, 68° N, are in nearly the same latitude. Reykjavik is on the south coast of Iceland, and its marine climate has an annual temperature range of only 20 degrees F; Verkhoyansk, deep in the interior of the great Asian land mass, has a continental climate with an annual range of almost 120 degrees F.

Summarizing, *ocean areas have marine climates with a small yearly temperature range; continental interiors have continental climates with a large yearly temperature range.*

4. Prevailing winds and temperature. While only small islands can have true marine climates, many places have what is known as a *marine west coast climate.* Such climates occur in the belt of prevailing westerlies, where the prevailing winds carry ocean air to the west coasts of continents in middle latitudes. Western North America, South America, Europe, and New Zealand receive the marine effect of the prevailing westerlies, as illustrated in the mild climates of Vancouver, B. C., and London, England. Far inland, as at Edmonton or Regina, the climate is truly continental and the temperature range is very large.

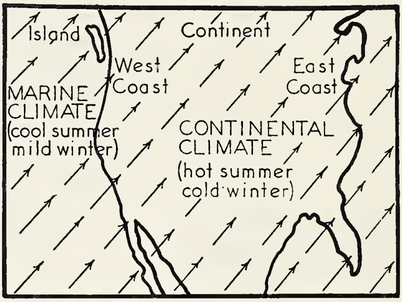

Fig. 14–3. The effect of prevailing winds on temperature.

On the east coasts, as at Halifax and St. John, the prevailing westerlies blow from the interior, bringing hot winds in summer and cold winds in winter. This gives the east coast a climate that resembles the continental climate of the interior much more than it does the marine climate of the west. The Atlantic Ocean, although close by, has little temperature effect on the east coast because the winds are usually "blowing the wrong way"—from the land rather than from the ocean.

To summarize: *in the belts of prevailing westerlies, west coasts have marine climates with cool summers and mild winters; east coasts have continen-*

tal climates with hot summers and cold winters.

5. Topography and temperature. High mountain ranges often keep out winds that might otherwise affect the temperature of a region. For example, the marine climate of the Pacific coast of Canada extends no farther than the west side of the Coast Range. On the east side of these mountains, only a relatively short distance from the sea, the interior valleys of British Columbia have some of the hottest summers found in Canada, and the winters may be 20 degrees colder than on the coast. Southern Italy owes its balmy climate partly to the fact that cold north winds are kept out by the Alps. In contrast to this, the level Great Plains of North America allow icy winds to sweep all the way from the Arctic Ocean to the Gulf of Mexico during many a cold wave of winter.

6. Ocean currents and temperature. The temperatures of some islands and coastal regions are greatly affected by ocean currents that are considerably warmer or colder than the normal for their latitudes. The effect of such currents is greatest when the prevailing winds blow from them to the land. In one famous example, the prevailing westerlies blow from the warm Gulf Stream to the shores of Iceland, the British Isles, and Scandinavia, giving these regions climates as warm as those of places many hundreds of miles closer to the Equator. London, England, is just about 700 miles farther from the Equator than Cleveland, Ohio, but its average annual temperature is actually higher than Cleveland's. As an example of the effect of a cold current, northern Labrador, chilled by the Labrador Current, has a yearly average more than 20 degrees lower than that of Stockholm, Sweden, in the same latitude! (See the isothermal maps of the world in Chapter 2 for many more illustrations of the effects of ocean currents on temperature.)

7. Summary of temperature factors. The factors that control the temperature characteristics of a region may be summarized as follows: (1) The higher the *latitude*, the colder the climate. Increase in latitude also tends to produce smaller daily temperature ranges but larger yearly ones. (2) The higher the *altitude*, the colder the climate. (3) *Sea or land locations* affect temperature ranges; sea areas have marine climates with small ranges, while land areas have continental climates with large ranges. (4) *The direction of prevailing winds* also affects temperature ranges. When winds blow from large bodies of water, temperature ranges are small; when they blow from large land areas, temperature ranges are larger. (5) *Topography* of the land determines whether winds from distant regions may affect the climate. (6) *Ocean currents* may make the climate of a region warmer or colder than the normal for its latitude.

FACTORS THAT CONTROL RAINFALL

8. Latitude and rainfall. The climatologist, like the baseball fan, wants to know not only the "final score" or total rainfall for the year, but also the "score by innings," or the monthly distribution of the rainfall. Latitude is as important in determining both these features of climate as it is in determining the annual and monthly temperatures. The latitude of a place determines the wind or pressure belt it is in, and these belts, in turn, are largely responsible for the wetness or dryness of the climate. (See Chapters 4 and 7.) Wind belts shift during the year. If a place's latitude is such as to keep it in a rainy belt all year, then its rains will fall fairly evenly throughout the year; if it stays in a dry belt all year, its lack of rain will persist throughout the year. But places over which both wet and dry belts pass during the year will have wet seasons and dry seasons at various times. (See Topic 10, Chapter 4.) The longer the wet belts remain, the longer the rainy seasons will be. Places nearer the centers of wet belts will have long rainy seasons and short dry ones; places nearer the centers of dry belts will have short rainy seasons and long dry ones.

Figure 14–4 shows how latitude alone tends to fix both the total annual rainfall and its monthly distribution. On such a basis the world can be roughly divided into zones of eight rainfall types. These types can be easily understood if it is borne in mind that the wind belts shift north in northern summer and south in northern winter.

In the tropics, from latitudes 0° to about 30°, four rainfall types occur. In Figure 14–4, Zone A represents the equatorial regions which are in the rainy doldrums all year. These regions have a large total rainfall, evenly distributed, with slight increases near the times of the equinoxes, when the sun's rays are vertical at the Equator. Zones B and C represent regions which are in the dry trades in their winter but are covered for some time by the rainy doldrums in their summer. (Remember that summertime in the Northern Hemisphere is wintertime in the Southern Hemisphere, and vice versa.) Zone B is nearer the doldrums, so it has a long rainy season and a short dry season. Zone C, farther from the doldrums, has a short rainy season and a long dry season. In both cases the rains come when their sun is

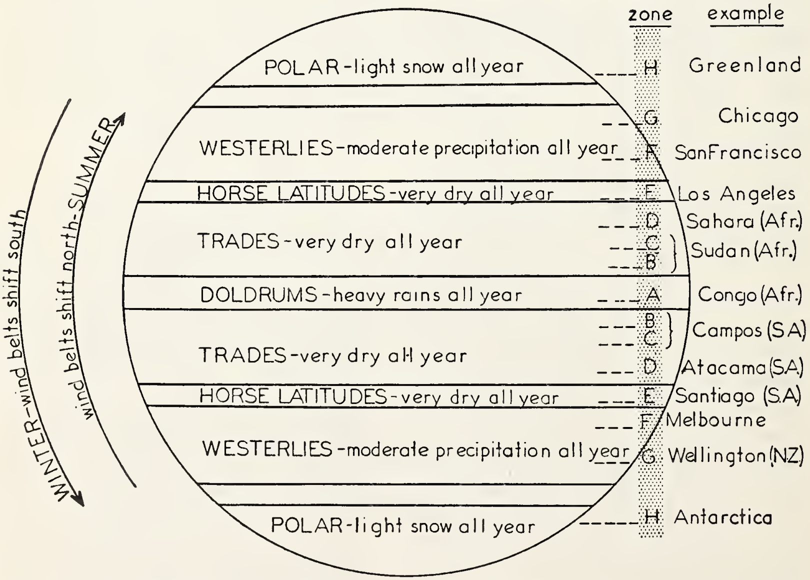
zone
example
POLAR-light snow all year
H
Greenland
G
Chicago
WESTERLIES-moderate precipitation all year
F
SanFrancisco
HORSE LATITUDES-very dry all year
E
Los Angeles
D
Sahara (Afr.)
TRADES-very dry all year
C
B
Sudan (Afr.)
DOLDRUMS-heavy rains all year
A
Congo (Afr.)
B
C
Campos (SA)
TRADES-very dry all year
D
Atacama (SA)
HORSE LATITUDES-very dry all year
E
Santiago (SA)
F
Melbourne
WESTERLIES-moderate precipitation all year
G
Wellington (NZ)
POLAR-light snow all year
H
Antarctica
WINTER-wind belts shift south
wind belts shift north-SUMMER

Fig. 14–4. How rainfall is related to latitude. Because of the shifting of wind belts, many of the places illustrated here have both rainy and dry seasons in the course of a year.

vertical. Zone D, in either the trades or horse latitudes all year, gets practically no rain at any time.

Outside the tropics, from latitudes 30° to the Poles, there are again four rainfall types. Here the principal sources of rainfall are the cyclones and fronts of the prevailing westerlies and the polar easterlies, instead of the convectional showers of the doldrums. Zone H in the Arctic and Antarctic regions and Zone G in the high middle latitudes have rain (or snow) fairly evenly distributed throughout the year. In Zone H the total precipitation is small because the cold air can hold little moisture. In Zone G the total is moderately large but generally not as large as in the warmer doldrums. Zones E and F are dry in summer when in the horse latitudes, and rainy in winter when the westerlies move over them. Zone E, farther from the westerlies, receives only brief, light winter rains; Zone F, in the westerlies a larger part of the year, has a moderate amount of winter rain.

9. Mountains and rainfall. It was explained, in the chapter on precipitation, that the windward sides of high mountains are rainy and the leeward sides are dry. This holds true in all wind belts, wet or dry, so that parts of normally dry belts may be wet, and parts of normally wet belts may be dry. The warmer the winds are, the more moisture they can carry, and the more rain they can drop. Wherever mountains occur in the normally warm, dry trade-wind belts, heavy rains fall on the windward eastern and northern slopes in the Northern Hemisphere, on the windward eastern and southern slopes in the Southern Hemisphere, and on the southern and western slopes of the Himalaya Mountains in India at the time of the summer southwest monsoon. These rains are usually seasonal rather than all year round as in the doldrums, but the total may be as large as or larger than that of the doldrums (see Figure 14–5).

Wherever mountains occur in the normally moist prevailing westerlies, the windward western slopes will be rainier than normal, but the leeward eastern slopes and land extending beyond them will be extremely dry. These dry leeward slopes are said to be in the "rain shadow" of the mountain. Just as an object that casts a shadow is keeping out light, so a mountain that casts a "rain shadow" is keeping out rain. Great deserts in Nevada, Arizona, and southern California are in the "rain shadow" of

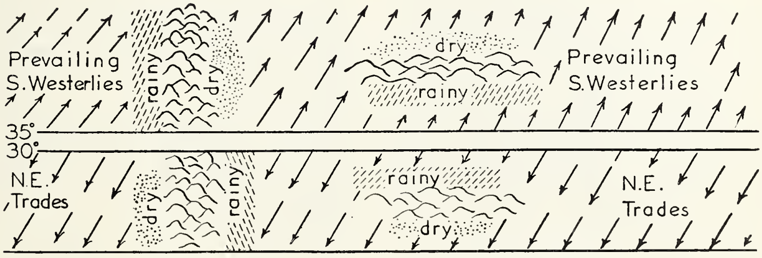

Fig. 14–5. The windward sides of mountains are rainy; the leeward sides are dry. This diagram shows how the rainy and dry sides are related to the position of the mountain and the wind belt in which it lies.

the Sierra Nevada. The dry areas of southern Alberta are in the rain shadow of the Rocky Mountains. On the other hand, the heaviest precipitation in Canada falls on the windward western slopes of the Coast Range in British Columbia.

The *foehn* wind of the Alps and the *chinook* wind of the Rocky Mountains are hot, dry winds that sweep down the leeward slopes of these mountains toward low-pressure areas at their bases. Heated by the compression of their descent, and warming up at the dry-adiabatic lapse rate of 5½ degrees F per 1000 feet, they sometimes melt the mountain snows so rapidly as to cause great avalanches, and may dry out valley grazing lands to such an extent that there is great danger of grass fires.

10. Distance from the sea. Nearness to the sea is no guarantee of sufficient rain fall. The desert of Peru, for example, is located next to the Pacific Ocean, yet it is one of the driest regions in the world. Its southeast trade winds come from the dry interior, and to make matters worse, this strip of Peru is on the leeward western side of the great Andes Mountains. But where winds do blow from the sea, rains are likely to be heavier nearer the ocean than farther inland, and heavier near warmer parts of the oceans. The total yearly rainfall of eastern United States is greatest along the Gulf and Atlantic coasts and decreases inland and northward.

Continental interiors are likely to have more rain in summer than in winter. The warm summer winds can carry more moisture, and convectional showers occur more often in summer.

11. Ocean currents and fogs. The most striking moisture effect of ocean currents is the production of *advection fogs* (see Chapter 6) along coastal regions. The frequent winter fogs of England and Scotland can be attributed largely to the fact that warm, moist Gulf Stream air, carried over the British Isles by the prevailing westerlies, is cooled over the land. The summer fogs of the Nova Scotia coast are formed when warm winds from the south are cooled over the cold coastal waters of the Maritimes. The fogs of Newfoundland occur when warm Gulf Stream air blows over the cold Labrador Current, while the summer fogs of the Pacific coasts of the United States, Peru, and northern Chile are caused by the blowing of warm ocean winds over cold coastal currents.

12. Summary of rainfall factors. The factors that control the rainfall features of climate may be summarized as follows: (1) The *latitude* of a place determines what one or more wind belts it will be in during the year. These wind belts are of primary importance in determining the total rainfall and its seasonal occurrence. (2) *Location on the windward or leeward side of a mountain* will mean either more or less rain than is normal for the place's latitude. (3) Where prevailing winds blow from the sea the *areas closest to the sea* generally receive the most rain. (4) *Ocean currents* that are much warmer or colder than their adjoining land or water are likely to produce fogs. The line where cold and warm water meet is often termed a *cold wall*.

HAVE YOU LEARNED THESE?

Explanations of: the difference between weather and climate; the factors that control temperature; the factors that control rainfall; the chinook wind

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Explain the relation between a place's latitude and its average yearly temperature, its yearly range in temperature, and its daily range in temperature. Give examples.

2. How does altitude affect climate? Give examples.

3. How do marine climates differ from continental ones in temperature? Why?

4. (*a*) How do prevailing winds determine whether a climate is marine or continental? (*b*) How do the climates of the east and west coasts of southern Canada differ in temperature?

5. How may topography affect temperature? Give examples.

6. Give examples to show the temperature effects of the Gulf Stream and the Labrador Current.

7. Name 6 factors that may affect the temperature characteristics of a climate. State the effect of each.

8. (*a*) How does latitude determine a place's rainfall? (*b*) Why do some places have rains throughout the year? (*c*) Why are some places dry all year? (*d*) Why do some places have wet and dry seasons? (*e*) Describe the 4 rainfall types of the tropics. (*f*) Describe the 4 rainfall types outside the tropics.

9. (*a*) Which are the rainy sides of mountains in the trade wind belts? in the westerlies? (Use compass directions.) (*b*) Which are the dry sides? (Use compass directions.) (*c*) What is meant by the rain shadow of a mountain? (*d*) What are chinook winds?

10. (*a*) Why is closeness to the sea no guarantee of rain? (*b*) How is closeness to the sea related to rainfall? (*c*) Why do interiors usually have more rain in summer than in winter?

11. What is the principal moisture effect of ocean currents? Illustrate.

12. List three factors that control the rainfall features of a climate.

GENERAL QUESTIONS

1. Why is the daily temperature range likely to be greater in mountain regions than at sea level?

2. How would the climate of an equatorial mountain differ from that of a mountain in middle latitudes? Use Mount Chimborazo in Ecuador and Pike's Peak in Colorado as specific examples.

3. In the doldrums belt, temperature ranges are small in the interior as well as in coastal areas. Why is the effect of land or sea less important here than in higher latitudes?

4. Explain the difference in meaning between weather and climate.

5. Why does the Gulf Stream have little effect on the temperatures of eastern United States? Why does the Labrador Current have so great an effect on the temperatures of Labrador?

6. How do the temperatures of different parts of Alaska illustrate the effects of ocean currents and prevailing winds?

7. From the summary in Topic 7, select those factors that influence the temperature characteristics of the climate in your locality, and explain what the effect of each one is.

8. Why are convectional rains so much more frequent in the doldrums than in the middle latitudes? Why are convectional rains more frequent in summer (in middle latitudes) than in winter?

9. Why should the rains of the western slopes of the Coast and Cascade ranges be so much heavier than those of the Rocky and Appalachian mountains?

10. Why does the chinook come down so much warmer than it was when it started up at the same height? (Look up the moist-adiabatic lapse rate in Chapter 6, Topic 9.)

11. Why should fogs occur along the California coast in summer, when the land is presumed to be warmer than the sea? (See Chapter 6.)

12. Explain the distribution and amount of rainfall in your home area on the basis of the factors listed in Topic 12.

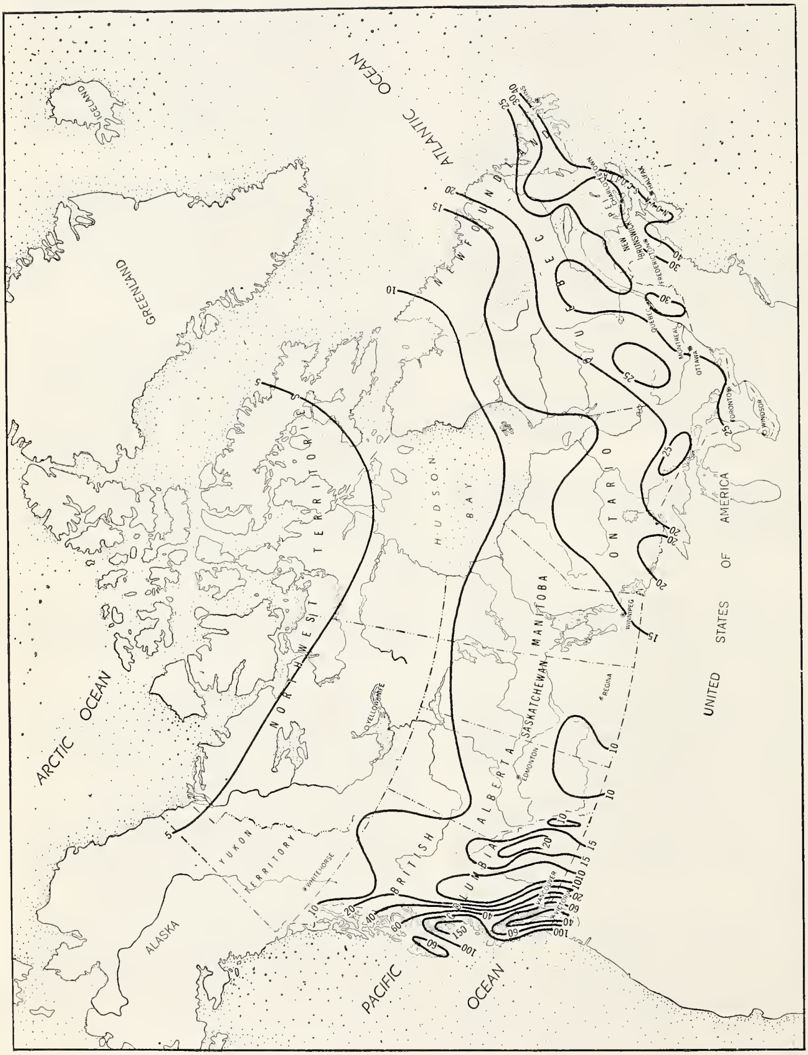

Fig. 14–6. Average yearly rainfall in Canada.

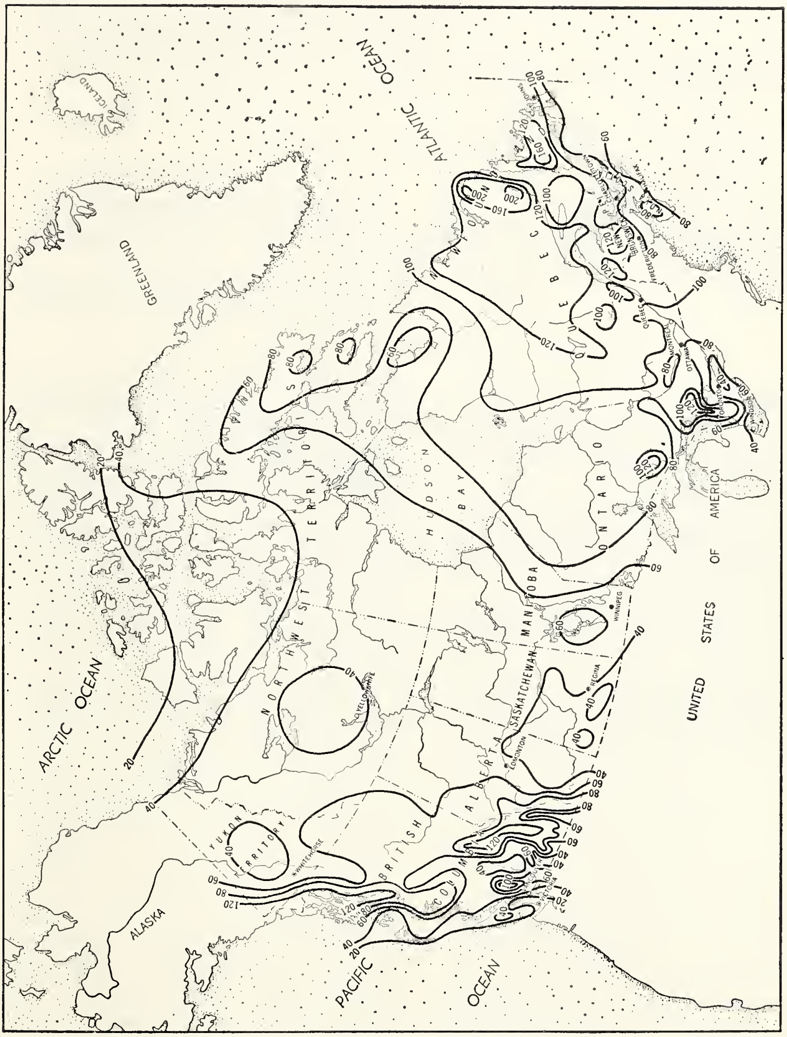

Fig. 14–7. Average yearly snowfall in Canada, in inches. To obtain the total annual precipitation for a given area, the amount of rainfall shown on Figure 14–6 has to be combined with the amount of snowfall shown above—with 10 inches of snow equivalent to 1 inch of rain.

STUDENT ACTIVITIES

1. Securing local weather records of average annual temperature, yearly range, and daily ranges. Analyzing them according to the principles explained in this chapter

2. Securing similar records for a place in the same latitude as your own, but at a different altitude. Comparing them with yours

3. Keeping local temperature, rainfall, and wind-direction records for an entire year, and analyzing them to discover the relationships between the first two and the last

SUPPLEMENTARY TOPICS

1. The Foehn in the Alps
2. The Chinook in the Rockies
3. The Climate of the Interior Valleys of British Columbia
4. Altitude Climates in the Tropics
5. Climatic Effects of the Gulf Stream
6. Climatic Effects of the Japan Current
7. Climatic Effects of the Labrador Current
8. Climatic Effects of the Peru Current

SUGGESTIONS FOR FURTHER READING

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Chapter 15

CLIMATE, SOILS, AND VEGETATION OF THE WORLD

1. Classifying Climates. Just as there are no two people who are exactly alike, so there are no two places that have exactly the same climate. However, many places in different parts of the world do have similar climates. It is, for example, well known that the climate of coastal British Columbia is like that of northwest Europe, and that the climate of parts of the Prairie Provinces is similar to the Russian Ukraine. Because of these similarities, climatologists find it useful to classify climates, just as the botanist finds it useful to classify plants, or the geologist to classify rocks, or the baseball coach to classify his players as infielders, outfielders, pitchers and catchers. One value of classification is economy. Suppose the scientist describes the general features of what he calls a "Mediterranean Climate." From that point on, no matter how many specific places having "Mediterranean Climates" he may describe, he need not repeat these general features. All he needs to do is to fill in the details or point out any differences.

2. Torrid, temperate, and frigid. An old elementary-school classification that is still well known to many is the division of the world into a "Torrid," or hot zone; two "Frigid," or cold zones; and two "Temperate," or in-between zones. The Tropics of Cancer and Capricorn and the Arctic and Antarctic Circles are the boundaries of these zones. Climates within these zones vary so widely that this classification is practically worthless, except for its meaning with regard to the length of daylight and the position of the sun in the sky. Since the tropics of Cancer and Capricorn are as far north and south respectively as the sun's vertical rays go, the Torrid Zone is simply the 47-degree wide belt between the two tropics, over which the sun's vertical rays pass during the year. The Frigid Zones, from the Arctic Circle to the North Pole, and the Antarctic Circle to the South Pole, are the "lands of the midnight sun." Here the sun stays above the horizon for 24 successive hours at one or more days at the time of the summer solstice, and below

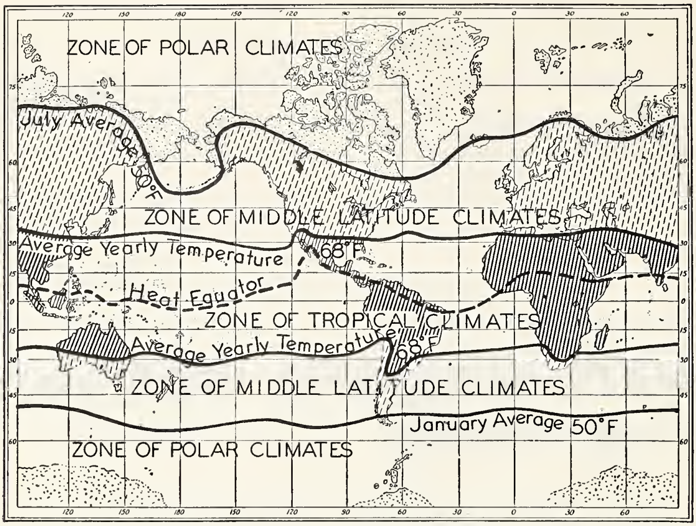

120
150
180
150
120
90
60
30
0
30
60
75
60
45
30
15
0
15
30
45
60
ZONE OF POLAR CLIMATES
July Average 50°F
ZONE OF MIDDLE LATITUDE CLIMATES
Average Yearly Temperature 68°F
Heat Equator
ZONE OF TROPICAL CLIMATES
Average Yearly Temperature 68°F
ZONE OF MIDDLE LATITUDE CLIMATES
January Average 50°F
ZONE OF POLAR CLIMATES

Fig. 15–1. This map shows the world divided into 5 climatic zones on the basis of temperature alone.

the horizon for as long a time at the winter solstice. Between the Torrid and Frigid Zones lie the Temperate Zones, one in each hemisphere from the Tropics to the Circles. Lying beyond the Tropics, these zones never receive the vertical rays of the sun as the Torrid Zone does, nor do they ever have 24 hours of continuous day or night as the Frigid Zones do.

3. Isotherms and climatic zones. Although classification of climate by latitude is not very valuable, a division of the earth's surface north and south of the equator into three divisions—*polar, mid-latitude,* and *tropical* climates has some significance. People of European descent find that the climates of the mid-latitudes are generally more pleasant to live in, whilst tropical areas, unless modified by altitude, are often too hot all the year round for comfortable work, and the polar areas are too cold for comfort. A rather similar division can be made on the basis of agricultural crops. The humid tropics grow one group of crops, such as rice, sugar and coffee; the mid-latitudes grow another, which includes wheat, barley, and various fruits such as apples and peaches, whilst the polar regions are too cold for any crops.

Modern climatologists use isotherms (*eye* so thermz)—lines on a map joining points of equal temperature—as boundaries for the polar, mid-latitude, and tropical climatic zones. The monthly isotherm dividing the polar and mid-latitude climates is the 50° F isotherm for the warmest month. This isotherm corresponds very closely with the poleward limit of trees (tree line). The monthly isotherm dividing the tropical and mid-latitude climates is generally taken as the 68° F (or sometimes 64° F) isotherm for the coolest month. Figure 15–1 shows a division of the world into 5 climatic zones using isotherms.

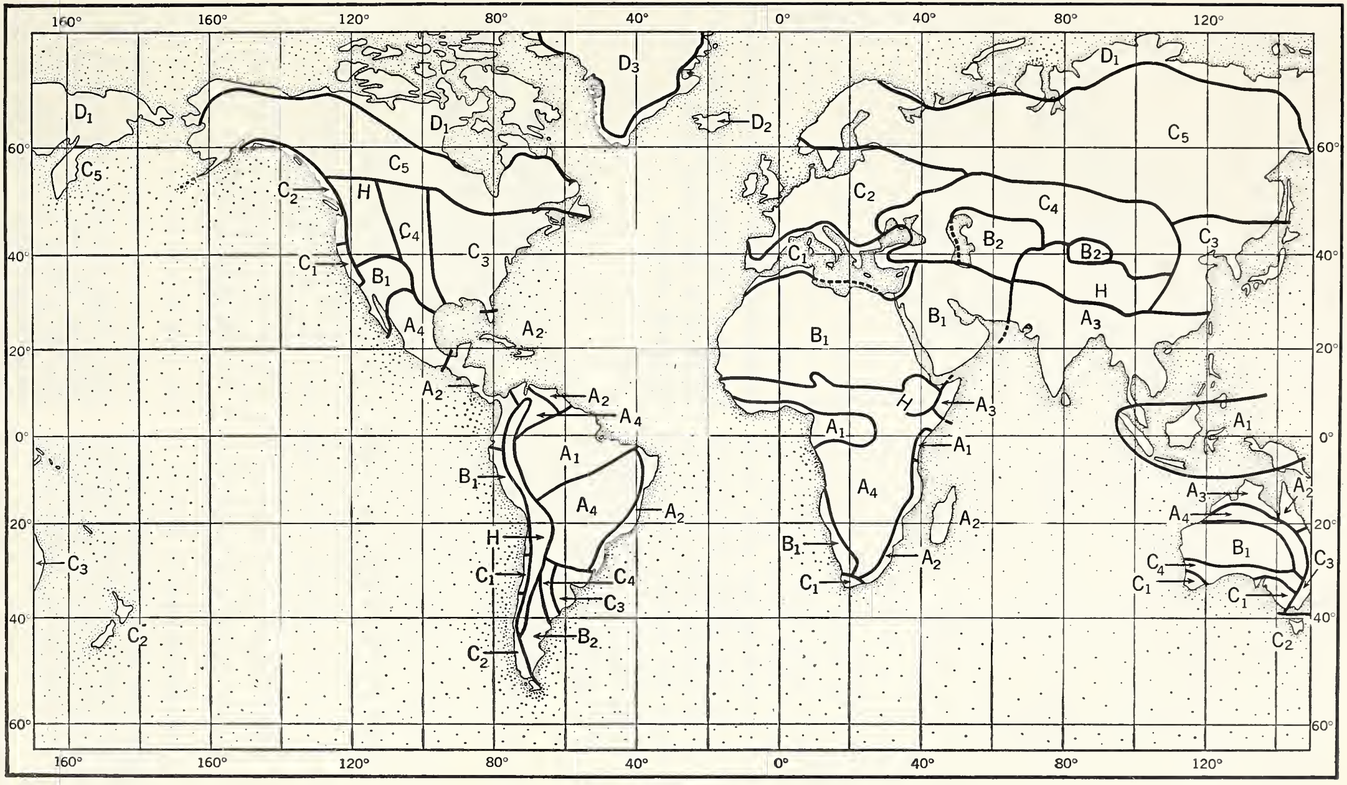


Fig. 15–2. The world divided into major climatic regions.

4. Modern classification of climates. A modern classification of climates usually divides the earth into the main temperature zones described above, and then subdivides these zones on the basis of the climatic features, such as ranges of temperature, annual precipitation, the seasonal distribution of rain and snow, and the amount of evaporation. Each combination of these features usually produces a distinctive cover of natural vegetation, such as jungle, pine forest, prairie grass, or desert scrub, which is an outstanding characteristic in a description of a region. In our classification, to be explained in the following chapters, we shall divide the climates of the world into three main groups, with some minor modifications from Figure 15–1. These groups are tropical, mid-latitude, and polar, which we subdivide into smaller, distinct areas based on the features mentioned in the beginning of this section. The climate types are listed below. They are shown on the world map, Figure 15–2, and on an 'ideal' continent in Figure 15–3.

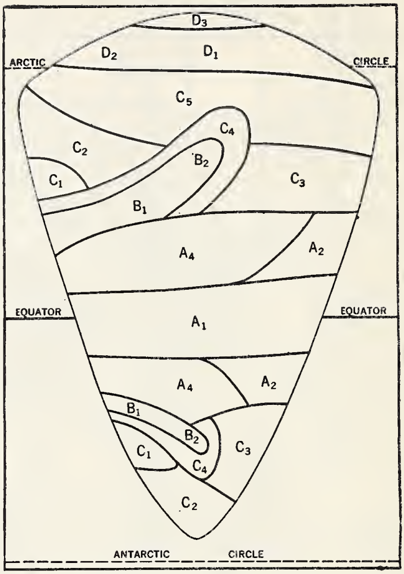


Fig. 15–3. The major climatic regions of the world as they would be found on a theoretical continent.

Tropical Climates	Humid	A1	Equatorial Rainforest
		A2	Tropical East Coast
		A3	Monsoon
		A4	Tropical Savanna
	Arid	B1	Tropical Deserts
Mid-latitude Climates	Humid	C1	Mediterranean
		C2	Marine West Coast
		C3	Humid East Coast
		C5	Subarctic
		C4	Mid-latitude Grassland
	Arid	B2	Mid-latitude Desert
Polar Climates		D1	Arctic Continental
		D2	Arctic Maritime
		D3	Ice Cap
Mountain Climates		H	

5. World Soil Classification. Soil is an essential part of the physical features, climate, and vegetation which influence man's activities on the surface of the earth.

Practically all soils are formed from weathered rock. With the exception of some steep mountain slopes, soils develop on all rocks, but the length of time for a deep soil to form depends upon the resistance of the rock and the rate of weathering produced by the climate in a given area. For example, during the last continental glaciation, the ice removed the soils from a great part of the Canadian Shield whose rocks are mainly granite, a very resistant rock. On this resistant type of rock the soil forms slowly, and only very thin soils have developed since the ice melted thousands of years ago. In other areas, particularly the southern half of the Prairie Provinces, and in the lowlands of Eastern Canada, thick deposits of clay and sand were left when the ice retreated, and these have formed the parent material for many good soils.

Certain rocks, of which limestone is the most important, always develop special soils. If there is sufficient length of time, however, most rocks develop the same type of soil in a given climatic zone, because climate is mainly responsible for soil development.

When a soil develops from unconsolidated (loose) material, its texture varies considerably. The soil texture depends on the size of the particles making the soil. A sandy soil has a coarse texture, as the grains are large; it often has low fertility and loses its moisture quickly during a drought as the pore spaces between particles allow water to go through it quickly. A clay soil, on the other hand, has a fine texture—the size of an average particle of clay being one-one millionth of an inch in diameter —and as the pore space is small, it will not allow water to pass through it, making it a heavy soil. However, it is often fertile, and produces good crops if well-managed. A silty soil has particles half-way in size between clay and sand, whilst a loam is a mixture of clay, silt, and sand.

6. Soil and climate. Rainfall, a major factor in climate, has an important part in the formation of soil. Water can move upward or downward in the soil depending upon the amount of rainfall an area receives. If the rainfall is heavy, with the surface always moist, the predominant movement is downward. If, as in arid areas, there are long dry periods, and the upper soil surface dries out, the water lower in the soil will come to the surface. Certain minerals in the soil are soluble in water; that is, they are capable of being dissolved, and carried by water. When water moves down through the soil into the ground these soluble minerals are carried with and deposited at a lower level in the soil where they are of little use to plants. This process is known as *leaching*, and occurs in areas of heavy rainfall, such as the tropical rainforest, where, consequently, the top soil is robbed of its plant food; although these lands support dense forests they are not very suitable for cultivation.

On the other hand, in arid areas, where the surface of the soil is usually dry, the water in the soil will come up to the surface, and bring with it soluble materials, usually salts, which are deposited on the surface. In some cases these salts form a white crust on the surface, and unless rain water takes them downwards into the soil again, the soil will be left infertile. However, not all dry lands are infertile. Such desert areas as the Imperial Valley, in California, support a great variety of crops when properly irrigated. Thus too little, or too much, moisture will take away the food so necessary to plant growth. It should be obvious, then, that the best conditions for plant growth lie somewhere between the two extremes.

In areas of heavy rainfall, large forests exist. From the trees and shrubs, material such as leaves, twigs, and branches fall to the ground. As the years go by this material becomes thicker and thicker, and the lower section of it decays. This decayed material is known as *humus*. This humus helps to improve soil fertility by providing nitrogen and other elements for the soil.

A mature soil, that is, one that is well-developed, has three layers or *horizons*. The A horizon contains weathered soil from which the finer material and soluble minerals may be taken; it also usually contains humus. The B horizon has no humus, and may contain materials that have been leached from A horizon. C horizon is the area where the soil joins the parent rock.

7. World vegetation. One of the most important geographical features of a region is the vegetation. When the plant cover has not been affected by man, it is said to be *natural vegetation*. There are few areas of natural vegetation in the world today. Even the northern forests of Canada and the U.S.S.R., which were once thought to be good examples of natural vegetation, are now known to have been modified in many ways by accidental fire. Where the natural vegetation has been replaced by types planted by man, we speak of the *cultivated vegetation*.

The type of natural vegetation found in an area depends upon climate, physical features, and soil. In the climatic group, temperature and rainfall are the most important. In cold climates, low temperatures are the most important factor restricting tree growth. The 50° F isotherm for the warmest month approximately marks the tree line. Low rainfall restricts the growth of trees in dry climates. It was soon discovered by climatologists that the amount of rainfall needed to support tree growth varies with temperature. Although 15 inches might support trees in a cool middle-latitude climate, 30 inches would be insufficient in a hot, tropical land. It is now believed that the type of natural vegetation depends on the ratio between evaporation (which in turn varies mainly with temperature) and rainfall.

There are four main classes of natural vegetation: (a) forests, (b) grasslands, (c) desert scrub, (d) tundra. In the forest area, precipitation is greater than evaporation; in grassland and desert scrub evaporation is greater than rainfall; and in the tundra, temperature (and often poor drainage) is the controlling factor.

Tropical forests and mid-latitude forests are not alike. In tropical forests, such as those found in the Amazon Valley, there are many types of trees, but no great stands of the same type. On the other hand in mid-latitude forests, such as the coniferous forest of northern Canada, there are only a few types of trees, such as spruce and balsam, which occur in great stands. This is important economically, as the pulp and paper industry in Canada depends upon huge stands of softwood, particularly spruce, being obtained from a single area. On the other hand, tropical trees, such as ebony, mahogany, and rosewood, which are valuable hardwoods, are difficult to find and remove as they are scattered singly throughout the forest.

It should be understood that coniferous forests (like those in northern Canada), deciduous forests (like those in northwestern Europe) and a mixture of both coniferous and deciduous trees (like those in southern Quebec and the Maritime Provinces) may be found in the *mid-latitude forest belt*. Similarly the evergreen forests of the hot, wet Amazon basin, and the semideciduous forests of Monsoon India are both found in the tropical forest belts.

The grasslands are similarly divided into those of the tropics, such as the tall elephant grass of parts of the Sudan, and those of the mid-latitudes such as the shorter grass of the Prairie Provinces and of the pampas of Argentina.

In the following chapters, the climate, soils, natural vegetation, and man's responses to them, will be discussed for the major climatic regions.

HAVE YOU LEARNED THESE?

Meanings of: isotherm, weathered rock, soluble materials, evaporation

Explanations of: humus, leaching, natural vegetation, cultivated vegetation, tree line

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Why do we classify climates?

2. (*a*) What are the boundaries of the so-called torrid, frigid, and temperate zones? (*b*) How are they subdivided?

3. (*a*) Into what three main types of climates do isotherms divide the world? (*b*) Why is it difficult to work in tropical areas? (*c*) Name the two isotherms that divide the world into three main climatic zones. What month is taken as the deciding factor in each case?

4. Name the climatic features that give a region its outstanding characteristics.

5. (*a*) What main factors affect soil formation? (*b*) From what material are practically all soils formed? (*c*) Why do soils develop at different rates? (*d*) Name a type of rock which is resistant to soil formation. (*e*) On what rock does a special soil develop? (*f*) On what does soil texture depend? (*g*) Name in order of size the materials that make up soil.

6. (*a*) How does water move in the soil: in wet areas? in dry areas? (*b*) Explain the term *leaching*. (*c*) As far as rainfall is concerned, what are the best conditions for fertile soil? (*d*) How does humus help to fertilize the soil? (*e*) How do minerals move from the A to B horizon? (*f*) In what horizon is humus found?

7. (*a*) Explain the difference between natural and cultivated vegetation. (*b*) What factors control vegetation? (*c*) What is the tree line? (*d*) How is it generally determined? (*e*) What determines the amount of evaporation in an area? (*f*) What are the four classes of natural vegetation? (*g*) Why are stands of one type of tree easier for lumber operations than areas where many types of trees grow together? (*h*) What difference is there between the grasses of tropical and mid-latitude climates? Explain why.

STUDENT ACTIVITIES

1. Making a visit to local areas with the provincial or federal soil map of the district to study different types of soil

2. Making a tour of your district to examine different types of vegetation

3. On a blank map of Canada draw the isotherms for the temperature on a given day, using the data published in the newspapers

SUPPLEMENTARY TOPICS

1. Other Classifications of Climate
2. Climate and Soils
3. Climate and Vegetation
4. Climate of the Past
5. Are Our Winters Becoming Warmer?

See list of suggestions for further reading at the end of Chapter 14.

Chapter 16

TROPICAL CLIMATES

1. Classifying tropical climates. The tropical climates are the hot climates of the world. The sun is overhead or nearly so in the middle of the day throughout the year. Solar radiation is always intense and temperatures are consequently high. A large part of this tropical belt lies over oceans where the rate of evaporation is high, and the hot atmosphere is usually saturated with moisture. In some parts of the tropical regions, such as the Amazon Basin, the winds carry the moist maritime air masses over the continents. These areas experience *tropical rainy climates*. Farther from the equator the heating power of the sun varies from season to season; and, moist air masses do not penetrate the continents in winter, although they may still be present in summer. These areas form the *tropical savanna* climatic region. On the poleward side of these areas, winds known as trade winds, usually blow towards the equator and the weather is controlled for long periods by anticyclones (Chap. 4, Fig. 4–14, 4–15). Moist, maritime tropical air never enters this area and there is almost no rainfall. This is known as the *tropical desert* climatic region. The Sahara is an example of this type of climate.

2. Tropical rainy climates. Three important varieties of the tropical rainy climate are the equatorial rainforest, the tropical east coast and the tropical monsoon types.

The *equatorial rainforest* climate is restricted to tropical oceanic islands, to some equatorial coastal areas and to a few regions where the humid maritime air masses can penetrate into the interior of equatorial continents. The most extensive areas are found in Indonesia, in the Amazon Valley of South America, in the Congo Basin and along the Guinea coast of Africa.

Temperatures are uniformly high and there is little variation from day to day in the equatorial rainforest. On many tropical islands, the mean annual range is less than 1°. The daily average temperature in the equatorial rainforest is about 80° throughout the year. Only rarely does the thermometer go very much above 90. The highest temperatures ever recorded are generally lower than the highest temperatures which occur in most summers in southern Canada. At night the temperature in the equatorial rainforest may fall to 70°, but will probably never drop lower than 65°. Although these temperatures are not extremely high, their repetition unchanged day after day throughout the year, combined with high humidities, makes this climate very trying for people from North America and Europe.

Rainfall is heavy and evenly distributed throughout the year with no dry season: there are often wetter periods in 'spring' and 'fall' shortly after the equinoxes when the sun has been directly overhead at noon. The average rainfall is about 100 inches but it varies, being greater over the oceans and in the hilly areas, least over sheltered land areas particularly in central Africa. The rain falls from thunder clouds and normally occurs in the afternoon or evening, after a fine morning. Examine the graph shown in Fig. 16–1.

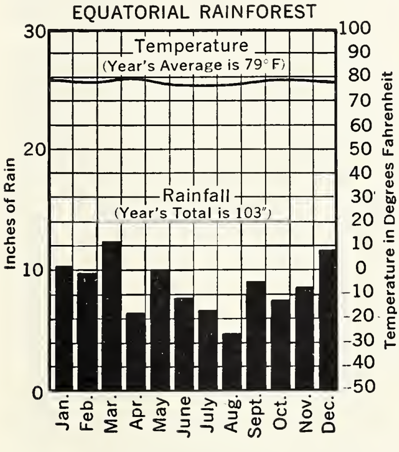
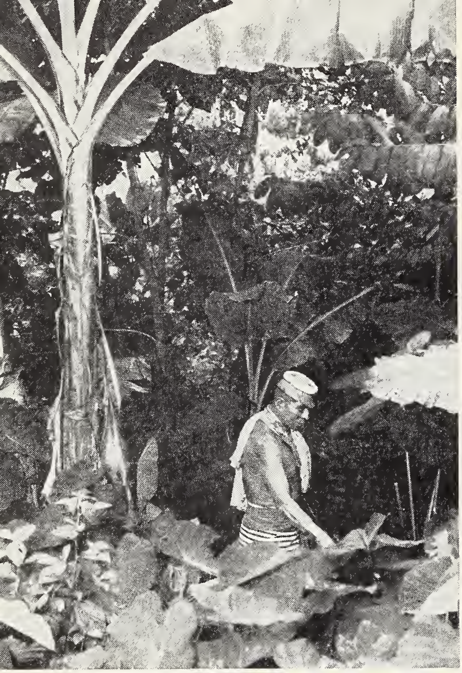


Fig. 16–1. This graph shows both average temperature and average rainfall for each month of the year in the city of Iquitos, Peru in the Amazon Valley of South America. The *temperature* is shown by the heavy line, the scale for which is given at the *right* side of the diagram. The *rainfall* is shown by the bar graph, the scale for which is given at the *left* side of the diagram. The graph shows the outstanding characteristics of this climate to be its uniformly high temperature and its uniformly heavy precipitation.

The Amazon Basin is probably the largest area of uniform climate in the world. It receives its moisture from the Atlantic Ocean but, rather surprisingly and for complex reasons, the rainfall increases towards the Andes in the west. Most of the Amazon Basin is a little south of the Equator and the heaviest rainfall occurs during the 'summer.' The rainfall of the Congo Basin is 10–30 inches less than the Amazon mainly because easterly winds from the Indian Ocean have difficulty in entering over the east African Plateau. The equatorial area of Indonesia has a higher precipitation than the other two areas because it is mountainous and is completely surrounded by warm seas.

The natural vegetation of the equatorial rainforest is the *selva*, a luxuriant, evergreen, broadleaf forest containing many different types of trees. In northern forests, such as those of the Canadian Shield, one or two types of trees such as the spruce and fir may be found over large areas. The selva, however, always contains a great many different types of trees. Trees in the selva vary in height with the tallest of the trees reaching more than 150 feet above the ground forming a nearly solid canopy. On the floor of the forest it is dark through lack of sunlight, and the undergrowth, consisting mainly of ferns, is not unusually dense. Jungle conditions with dense undergrowth, which makes the forest difficult to penetrate, are only characteristic of river banks and abandoned farm clearings.

Some of the trees found in the selvas are mahogany, rosewood and ebony. Trees such as these may be cut and shipped to other lands where they are in demand for the construction of fine furniture.



Courtesy Braniff Airways

Fig. 16–2. In the jungle or tropical rainforest of Ecuador.

Lumbering in the equatorial rainforest presents many problems. Trees of the same type do not grow side by side, so the men who cut the trees must move from one spot to another in the forest as they choose trees suitable for cutting. The forest is hot and it is wet from heavy rains. Insects are numerous. As trees chosen for cutting are tall, smaller trees must be cut to make a path into which the tree selected for cutting can be felled. After cutting the trees into lengths suitable for handling, they must be hauled to the nearest river. There are few roads which can be used. Some trees can be shipped by boat to the nearest port, while others may be allowed to dry for possibly as long as a year. When the trees are dry enough to float, they are tied together to make a raft and are towed or floated downstream.

The soils in the tropical rainforest are deep but not very fertile. Although a dense forest is able to grow on them, they are difficult to work agriculturally because of their low fertility.

The equatorial rainforest is a thinly populated region with a density of less than 2 persons per square mile, except in parts of Indonesia, where on rich volcanic and alluvial soils it may exceed 800 persons per square mile. Some of the native peoples live by hunting and collecting fruits, roots and nuts. Many of the people of the Congo and Amazon basins live in this way. The majority of the population are, however, subsistence farmers. That is, they raise enough food to supply their own needs. The farming may be of a primitive character, with cultivation shifting from clearing to clearing every few years when the soils have lost their limited natural fertility. These people do not plan to clear all trees and stumps from their fields, as a farmer does in our land, but plant crops among the dead trees. Since it is not usual to add fertilizer to the soil under such conditions, a good crop can be grown only two or three times. The fields are then abandoned and a new clearing is started. Naturally these people do not have to buy land as a farmer in Canada does. Crops vary from one area to another but include cassava (manioc), yams, corn and taro.

Native farming in a few areas, such as Java, is more stable and in such regions rice is often the main crop. Commercial farming, particularly in Africa and Asia, has developed on small native farms and European plantations. Cacao, peanuts, sugar cane, bananas, rubber and palm oil may be produced. Many foods which we use are also raised in these lands. Some of these are vanilla, spices (such as pepper, cloves, ginger, cinnamon), cocoanuts and pineapple.

3. Tropical east coast climates. Tropical east coast climates are found on the east coasts of continents north and south of the equatorial rainforest climate. In the Western Hemisphere they are well-developed in Central America, the West Indies and the Guianas on the north side of the Equator, and along the Brazilian coast south of the Equator.

In Africa a similar climatic region is found south of the equator in Portuguese East Africa, Natal and Madagascar. A tropical east coast climate is also found in Queensland, Australia. This climatic type is not found on the east coast of Asia, where the monsoon effect is too strong for it to develop.

The tropical east coast climate is farther from the Equator than the equatorial climate, and therefore shows more seasonal variations of temperature and rainfall. The main climatic control is the *trade winds* (from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere). These winds ensure a regular rainfall on exposed coasts on the eastern sides of continents. There is no dry season although there may be months with much heavier rain than others. The wettest period is usually in the summer, when the convectional rains of the doldrum belt have moved polewards, or in the early autumn when tropical hurricanes bring very heavy rain. The total rainfall varies considerably. Rainfall is usually over 40 inches (Rio de Janeiro, Brazil 43 inches; Havana, Cuba, 45 inches), but rainfall may be less where an area is sheltered from the trade winds by mountains (Kingston, Jamaica, 29 inches). Hurricanes are found in all tropical east coast regions except South America.

Temperatures in the tropical east coast climates are constantly high, the average temperature generally varying from 75°–85°. Although the temperatures are uniform, the weather is less trying than in equatorial climates because of the slightly greater range and the cooling effect of the trade winds.

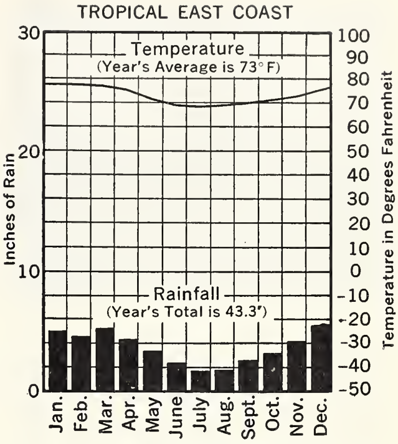


Fig. 16–3. This graph shows average temperature and average rainfall for Rio de Janeiro in Brazil. The outstanding features of this climate are the high temperatures all year round, and the moderate-to-heavy rainfall that reaches a maximum in the summer months, December–March.

The natural vegetation in the wetter areas of the tropical east coast climate is indistinguishable from the equatorial rainforest. Where the rainfall is less, the forest becomes lighter and is semi-deciduous in character, with most of the leaves being shed in the dry season. Trees are spaced farther apart, are somewhat smaller in size and the undergrowth becomes a dense, thorny mass of vegetation. The soils are similar to those of the equatorial rainforest but are rather more fertile. Since rainfall is lighter, leaching is not so intense.

Some of the richest tropical agricultural areas have been developed by Euro-

G. Merrill

Fig. 16–4. The coast of St. Kitts, B.W.I. This is a volcanic island. Sugar cane is growing in the foreground. The West Indies are in the Trade Wind belt and have a tropical east coast climate.

peans in this climatic type. The areas do not support a large population, but economic returns are high when the soil is carefully cultivated and soil erosion is controlled. A great variety of crops is grown on both small native farms and on plantations. Among the most valuable are coffee grown in Brazil and Venezuela, cacao in Brazil and Africa, sugar cane in Brazil, Natal and northeast Australia, and sugar cane and cotton in the West Indies.

4. Tropical monsoon climates. Tropical monsoon climates are found in India, Pakistan and southeast Asia. Limited drier tropical monsoon climates occur in Ethiopia and Somaliland in East Africa and in northern Australia.

When you studied the atmosphere's changing winds in Chapter 4, you learned something of the monsoon winds. The best developed monsoon winds in the world are found over India, southeast Asia and the Indian Ocean. In summer, the hot northern interior of India causes the formation of a great low-pressure area. The relatively cooler Indian Ocean becomes a centre of high pressure. The summer monsoon therefore blows from the ocean to the land, but being deflected to the right according to Ferrel's Law, it becomes a southwest wind over southern India. This warm, moist summer monsoon, blowing steadily from the ocean from June to September brings a long, rainy season to India. This is referred to as the wet monsoon.

In winter the cold interiors of southern Siberia and India produce a high pressure area. Winds blow from this area southwards to the lower pressure areas over the relatively warmer Indian Ocean. These winds, the winter monsoon, are deflected to the right and become northeast winds. They bring cool, dry weather from November until April when once again the air over India begins to warm rapidly.

The effect of these winds is to give a climate not unlike the tropical east coast except that the rainfall is heavier and more variable, the dry season is longer

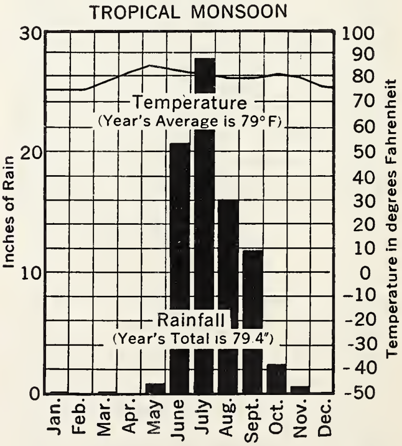


Fig. 16–5. The climate of Bombay, India. The southwest monsoon breaks early in June and there are then four months of very wet and slightly cool, although extremely humid, weather.

and temperatures vary considerably from month to month.

Rainfall and temperatures in the Indian subcontinent are extremely variable. The first part of the year is generally dry with high and increasing temperatures towards the end of May. In central India, temperatures exceeding 110° in the shade are common at this time of the year. The southwest monsoon "bursts," usually with an intense storm, sometime in June. The air temperature drops several degrees and for the next three or four months there are heavy rains with moderately high temperatures before the monsoon "retreats" in October. Most places receive annually over 50 inches of rain, and Cherrapunji in Assam, the wettest place in the world, receives 457 inches. In areas sheltered by the mountains, notably the Deccan Plateau, the rainfall is lighter and may not exceed 20 inches. The winter northeast monsoon is dry except along the southeast coast of India and northern Ceylon, where it brings rain from moisture picked up when the winds cross the Bay of Bengal. Northwest India also has a little rain in winter which it receives from mid-latitude cyclones.

The typical natural vegetation of the monsoon areas is a light forest with a heavy undergrowth of bushes and grass. It varies considerably, however, from dense almost equatorial forest where the rain is very heavy, to scrubland and grassland where the rainfall is lightest. In areas of dense population, such as the river basins, the forest has been cut down to make way for farms. Usually there are fewer types of trees and they grow farther apart than in the rainforest. In the dry season, most trees shed their leaves.

The soils of the monsoon lands vary considerably. The best developed soils are reddish in colour, similar to those in the tropical savanna.

The Asian monsoon lands are primarily areas of subsistence farming on very small holdings. Population density is high where the rainfall is heavy and the soils rich. In south China where the wet period is prolonged, rice is grown with two successive crops on the same land. In East Pakistan and India rice is grown on the wetter parts but the rainfall is often too low. Where water is available, irrigation is often used. In the drier areas, such as the Indian Deccan and central Burma, the rainfall is unreliable and millet is the chief food crop.

Commercial crops are grown on plantations and smaller farms where the population is not too dense. Crops include tea in the hilly areas of Assam and Ceylon where rainfall is high, and cotton, especially east of Bombay area of India. Most of the world's jute is grown on the Ganges delta. Burma and Thailand raise large quantities of the rice. Here, there is sufficient rice to feed the population and large quantities are exported from these two countries.

5. Tropical savanna climate. The climate of the interior and of the west

Fig. 16–6. Rhinoceroses in the savanna region of South Africa.

Courtesy South African Railways

coasts of the continents is very different from that of the east coasts in the same latitude. The trade winds still blow, particularly in winter, but they are now dry winds blowing from the tropical deserts. During the winter, the humidity is extremely low and there is no rain. As spring comes, the sun's radiation increases, the temperature rises and the daily average temperature may exceed 90°, with the highest temperatures at times reaching over 100°. The soil is parched, the vegetation dies and the sky may be filled with the smoke from bushfires. By late spring, moist air associated with the shifting doldrums belt begins to move into these areas. Violent storms often occur. In West Africa these storms are known as tornadoes. Heavy rains follow throughout the summer and temperatures drop slightly. In the fall the rains decrease and, for a short time, the temperature may rise again before winter sets in. The tropical savanna climate is really transitional between the tropical rainy climate and the tropical desert. On the equatorial side of the region the savanna rains may last 9 or 10 months and the yearly total may exceed 50 inches. On the poleward side the rains may only last 4 to 5 months and the total may be less than 25 inches.

Tropical savanna climates are found in the interior of Venezuela (the llanos) through much of the interior of Brazil (the campos) and in the interior of Africa, south of the Sahara Desert (excluding the Congo Basin) where, however, the temperature is often modified by altitude. This climate is also found in parts of northern Australia. A modified variety of savanna climate is present on the Mexican Plateau. In some dis-

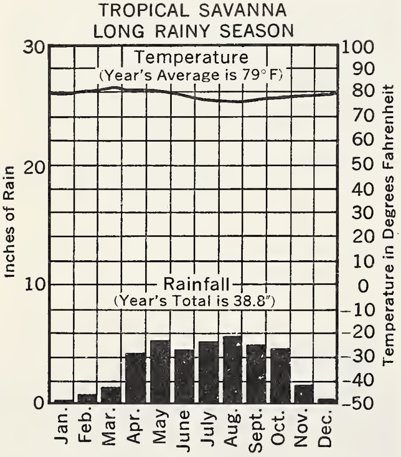


Fig. 16–7. This graph shows average temperature and average rainfall for Mongalla in the Sudan, Africa. The outstanding features of this tropical climate are its rainy summer, its dry "winter," and its uniformly high temperature with somewhat greater range than the tropical rainforest climate.

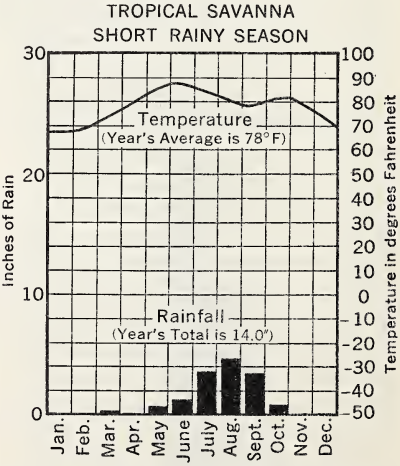
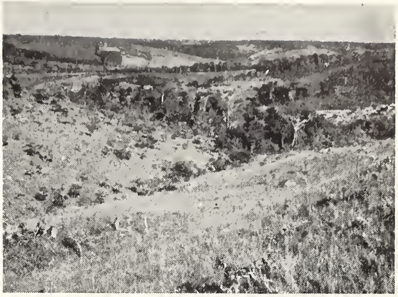


Fig. 16–8. This graph shows average temperature and average rainfall for El Obeid in the northern Sudan, farther from the Equator than Mongalla. Still very hot, El Obeid has a larger temperature range, a shorter rainy season, and much less rainfall than Mongalla.

tricts of India and Australia the monsoon and savanna climates are very similar. However, since the causes of these two climates differ, they are given different names.

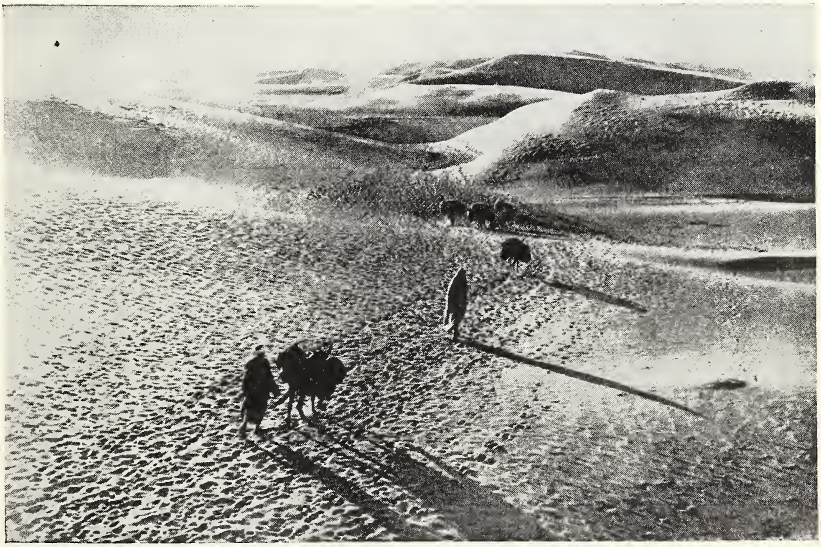
The savanna is a tropical grassland. The grasses occur in thick tufts often 6 feet high and occasionally exceeding 12 feet in the case of elephant grass. Clumps of low, umbrella-shaped trees, including palms and acacias grow where groundwater is present, and dot the landscape like trees in a park. Along the rivers, the forest is almost continuous. The African grasslands are the home of many wild animals including great herds of antelopes, giraffes, lions, buffaloes and elephants.

The typical savanna soils are red. They are deep, and when first cultivated are fertile soils. They soon lose their fertility, however, and are very easily eroded. The lack of reliable rains and the presence of disease, especially among cattle in Africa, restrict the uses of the tropical grasslands. In Africa these lands are occupied principally by pastoral nomadic peoples. In the campos of Brazil, the llanos of Venezuela and in north



T. L. Hills

Fig. 16–9. The campos of Brazil have a tropical savanna climate. In this picture the land has been roughly divided into fields for farming.



Courtesy French Press and Information Service

Fig. 16–10. The North African desert in Morocco is a barren region of sands and sand dunes.

Australia cattle ranching is carried on. When a water supply is assured by irrigation, as near the Nile in Sudan, good crops of cotton, grains and tobacco are obtained. Elsewhere subsistence tropical farming is practised.

6. Tropical deserts. The tropical deserts are the hottest, driest areas of the world. Tropical deserts are found in a broad belt across north Africa (the Sahara and Libyan deserts), throughout Arabia, in Iraq, Iran and Pakistan. Smaller tropical deserts are found in southwest United States, northwest Mexico, in Peru, northern Chile, southwest Africa and central Australia. Unlike the other tropical climates, tropical deserts have a large daily range of temperature, with an occasional difference of 50 or 60° between day and night temperatures. The annual range of 20 to 30° is also greater than is normally found in the tropics. During the summer, the daytime temperatures usually exceed 100°. Near Tripoli a shade air temperature over 136° was recorded in 1922. Nighttime temperatures of about 75° feel cold in comparison. The daily average temperature in summer is normally over 90°. The high temperatures are often accompanied by local whirlwinds (dust devils) and sometimes by more prolonged, hot dust storms known as simoons in North Africa. In winter temperatures are cooler, averaging 55 to 75° depending to a great extent on latitude. Occasional frosts may be recorded at desert weather stations. The annual rainfall is very low, usually less than 5 inches. At Cairo, Egypt, the annual rainfall averages 1.2 inches and at Yuma, Arizona, 3.3 inches. At Iquique, Chile, no rain whatever was recorded for a period of 14 years. It is hardly possible to talk about an average rainfall. In such areas during a sudden storm, 2 inches of rain may fall in 2 hours. Such storms may cause heavy flooding for

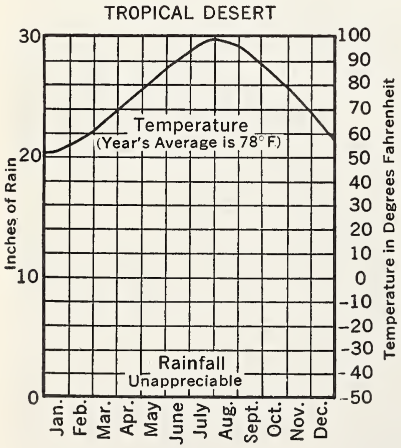


Fig. 16–11. Climate graph for In Salah in the Sahara Desert region of French West Africa. Note the large annual temperature range, with very hot summers and cool "winters." There is almost no rain.

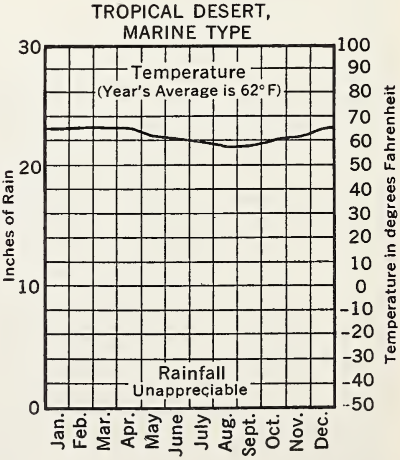
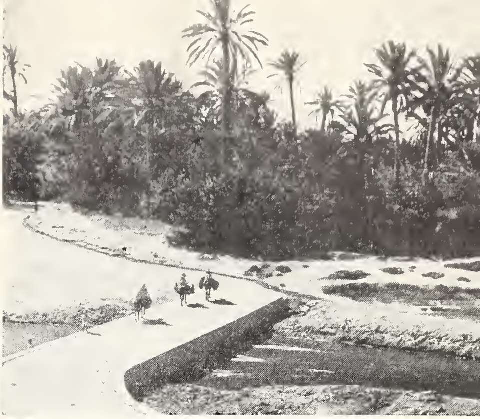


Fig. 16–12. Climate graph for Walvis Bay, South-West Africa. On tropical desert coasts that are near cold ocean currents the temperature is low for the latitude and remarkably constant.

there is little vegetation to prevent a rapid runoff. In the absence of rain there are extremely low humidities, few clouds and almost continuous sunshine.

A marine variety of the tropical desert climates is found on the western margins of the hot deserts where there are cold ocean currents near the coast. These desert coasts have surprisingly low temperatures for the latitude. The average temperature for the hottest month will not exceed 70°, and the coolest month has an average temperature of about 60°. Unlike other deserts the humidity is high and there are clouds, fogs and heavy dews. There is, however, little rainfall. These special conditions are found only within about 100 miles of the coast.

Very few deserts have no vegetation. Even in sandy deserts clumps of coarse grass and cactus-like plants can be found. After a rain shower seeds, which have been lying dormant for years, will start to grow and, for a short time, the desert will be covered with flowering plants. Desert soils generally contain too many soluble salts and too little organic material to be very fertile. Where there are alluvial soils, as in the valley of the Nile, irrigation may turn a barren area into a highly productive farmland. Natural irrigation is found around oases. An oasis is either a spring, which receives its water from underground artesian sources, often from mountains many miles away, or a river running through the desert but rising in mountains where rainfall is heavy.



Courtesy French Press and Information Service

Fig. 16–13. The approach to the Oasis de Gabes in Tunisia, North Africa. Here palm trees flourish amid desert surroundings.

Few persons live in the interior of deserts but primitive and more advanced peoples inhabit the desert margins. The Bushman of southwest Africa is primarily a hunter, who also gather roots from desert plants. The North African and Asian deserts are occupied by pastoral nomads wandering with their herds of sheep, goats, camels and horses. Surplus animal products are traded with desert traders and with farmers for grain and other agricultural products.

Irrigation has been developed along some of the larger desert rivers such as the Nile, Indus, Tigris and Euphrates. These areas now produce significant quantities of cotton, dates, rice, wheat and other grains.

HAVE YOU LEARNED THESE?

Meanings of: selva, subsistence farming, equatorial rainforest, monsoon winds, savanna, desert, oasis, campos, llanos

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) Name three types of tropical climates. (*b*) In which of these climates will rainfall be heaviest?

2. (*a*) What features are common to all tropical rainy climates? (*b*) Which type of tropical rainy climate is found in the

Congo Basin? (*c*) Why are equatorial rainforest climates trying for people from North America? (*d*) What do you understand by the term selva? (*e*) Name some of the products of the equatorial rainforest climate which we use in Canada.

3. (*a*) Locate, using your atlas, areas having a tropical east coast climate. (*b*) Why is this climate found on the east coasts of continents? (*c*) Why is rainfall heaviest during the 'summer' in this type of climate? (*d*) Name two products which we import from Brazil.

4. (*a*) State the chief causes of the monsoon type climate. (*b*) In which parts of the world is monsoon type climate found? (*c*) What are the main crops of the monsoon lands? (*d*) Name the place which has the heaviest rainfall in the world.

5. (*a*) During which part of the year do rains fall in the savanna? (*b*) Why is 'winter' the dry season on the savanna? (*c*) Describe the vegetation of the savanna. (*d*) Why does man make little use of the savanna?

6. (*a*) Name some parts of the world where tropical deserts are found. (*b*) What is an oasis?

GENERAL QUESTIONS

1. Why are tropical soils generally infertile?

2. Why are the largest monsoon areas in Asia?

3. Compare the times of the wet and dry seasons in the Northern Hemisphere savanna and Southern Hemisphere savanna.

4. Why does the temperature sometimes rise in the fall in monsoon and savanna climates?

STUDENT ACTIVITIES

1. Working out climatic graphs from data

2. On an outline map of the world, shade areas having tropical rainy climates. Use a different colour for each type of climate. Draw a legend

3. On a world map mark by name the chief tropical deserts of the world. If possible draw arrows to show the trade winds in these regions

4. On a map of the world mark the names of the following products in regions where they are produced on a large scale: rice, rubber, jute, cacao, coffee, sugar cane, cotton, tea

SUPPLEMENTARY TOPICS

1. Animals of the Tropical Forests
2. Jungle Insects and Tropical Disease
3. Tropical Plantations
4. Primitive Tropical Tribes
5. How White Men Live in the Tropics
6. Savanna Animals in Different Lands
7. Savanna Vegetation, Natural and Cultivated
8. Plants and Animals of Tropical Deserts
9. Desert Oases
10. Irrigation
11. Man in Tropical Deserts

Chapter 17

MID-LATITUDE CLIMATES

1. Classification. The mid-latitudes may be thought of as those regions that lie between the tropics and the polar regions. In terms of the climate, they are the regions which have at least one month of the year with a mean temperature below 64° and one month above 50°. Towards the Equator, these climates merge into those of the tropics and towards the poles they merge into the arctic and antarctic climates. The mid-latitude climates are influenced by both polar and tropical air masses, and they are, therefore, areas where the weather either changes rapidly from day to day or abruptly from season to season. There are six main types of mid-latitude climate: *Mediterranean* (or dry subtropical west coast), the *marine west coast,* both found primarily on the west side of continents; the *mid-latitude grasslands* and *mid-latitude deserts* found in the interior of the continents; the mid-latitude *humid east coast* type, and, on the north side, the *subarctic* type. The mid-latitude climates are extensive in the Northern Hemisphere; however, because in the same latitudes the land masses of the southern continents taper to points and are narrow, these climates are more restricted in the Southern Hemisphere. In fact, the subarctic type is not found at all in these lands.

2. Mediterranean climate. The Mediterranean type of mid-latitude climate is characterized by mild, damp winters when the weather is dominated by maritime air masses; and by hot dry summers when continental or descending anticyclonic air is dominant. Eastwards (moving inland), the Mediterranean climate rapidly becomes drier and gives way to grassland or desert. This type receives its name because the largest (and longest settled) area having this kind of climate

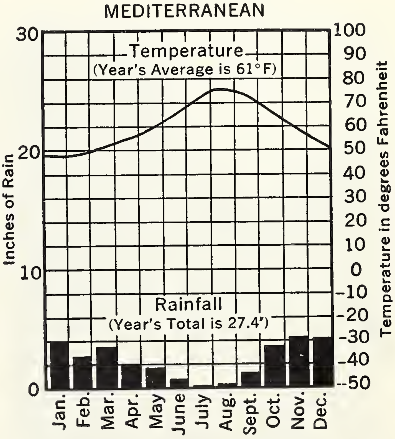
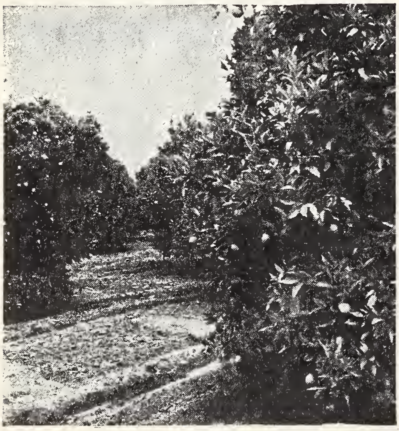


Fig. 17–1. The climate of Algiers, on the Mediterranean Sea Coast of North Africa. Note the warm dry summer and the mild rainy winter.

is found around the shores of the Mediterranean Sea in southern Europe and North Africa. Nowhere else does this climatic type extend so far inland; this is due to the influence of the Mediterranean Sea and the absence of mountain barriers in the region.

Limestone is a common rock around the Mediterranean Sea. Where limestone is found, the surface streams often disappear underground (see page 52, Book I). The resulting *karst landscape* appears more desert-like than the local rainfall might lead one to expect. Other areas with a Mediterranean climate include southern California, central Chile, the southwest corner of Cape Province in the Union of South Africa, southwest Australia and the region around Adelaide, Australia.

The temperature of the coolest month in Mediterranean areas varies between 40° and 55°. The winters tend to be cloudy but are not unpleasant. They are considerably brighter than winters in more northerly lands and periods of clear weather are common. Changeable conditions result from the typical stormy or cyclonic weather of mid-latitude lands. These may bring outbursts of polar air resulting in cold winds such as the famous *bora* which occurs in the north of the Adriatic and the *mistral* which blows down the Rhone Valley of southern France. Frosts may occur under such conditions, but they are rare and do not last for long periods. They are often fatal to crops, because early vegetables and citrus fruits that are commonly grown in Mediterranean climates are very easily damaged by frosts. Rain falls on about one day in four in winter. The total winter precipitation, which is mainly frontal in type, is fairly high, exceeding three inches a month at most places. Annual precipitation varies from 10 to 30 inches.



U.S. Bureau of Reclamation

Fig. 17–2. An orange grove in Southern California near Los Angeles. This is a region of "Mediterranean" climate.

Except along cool-water coasts, the summers are hot. Mean temperatures in summer months of 75° to 80° are usual with the maximum on many days often exceeding 90°. The temperature does not feel excessively hot because the humidity remains low. Hot winds occur which, like the cold winds of winter, have such distinctive temperatures and humidities that the local people give them special names. Such winds include the *sirocco* in North Africa and Italy, the *leveche* in Spain, the *brickfielders* in Australia and the *Santa Anna* in California. Generally in summer the skies are cloudless, and there is no rain. Desert weather prevails with absolute drought for two months or more. During this period, grassy slopes usually turn brown. Where there are cool currents offshore as in California and Morocco, conditions are also dry, but the summer temperature is 10 to 15° lower than inland and summer fog is widespread.

The native vegetation of Mediterranean climates is a mixed forest of low trees and woody shrubs. Trees do not shed their leaves and, because winters are never cold enough or summers dry enough, there is never a period when growth ceases. Plants find the hot summer drought difficult to survive, and they have developed many devices for reducing loss of moisture. Some tree trunks (such as the cork oak) are encased in a thick bark. Others have leaves which are small and leathery. Trees are often scattered across hillsides, widely spaced because each must have a large area of ground from which to draw its water. Where conditions are most favourable and rainfall is heaviest, the vegetation is an evergreen woodland with pine, cedar, and cork and evergreen oak. This forest is very limited especially in Europe, because accidental forest fires, cutting for charcoal and building purposes, and clearing for agriculture have all helped to remove it. Once the land has been deforested, drought, soil erosion and grazing by animals have prevented the woodland returning. In its place is a dense mass of shrubs and bushes 5–10 feet high known as *maquis* around the Mediterranean, *chaparral* in California and *mallee scrub* in Australia. As most areas are hilly and there is considerable limestone, the soils tend to be thin. However, in mountain basins deep, fertile alluvial soils are found. In the Great Valley of California, these soils, consisting of material carried down and deposited by many streams from the Sierra Nevada Mountains, are many hundreds of feet thick.

The climate of Mediterranean areas is excellent for grain farming. The restricted area of good soils and the demands of the relatively dense population to use of the land for other purposes limit the quantity that may be grown. Wheat is usually grown in winter. In summer, irrigation must frequently be used and, in southern Europe, this practice dates back to Roman times. Mountain streams are usually available to supply ample quantities of water. Large parts of the Mediterranean region cannot be irrigated, however, because they consist of plains, terraces or hillside slopes too far from sources of water. Summer pastures in such areas are consequently poor and dairy cattle are rare. In southern Europe, their place is often taken by goats. Vegetable growing and the raising of citrus fruit (both often aided by irrigation) are important agricultural industries. Two fruits, the vine and olive, have always been grown in the European Mediterranean region. They have been transferred successfully to other Mediterranean areas by European colonists.

3. Marine west coast climate. This type of climate is found in coastal British Columbia and the Alaska panhandle, northwest United States, north-

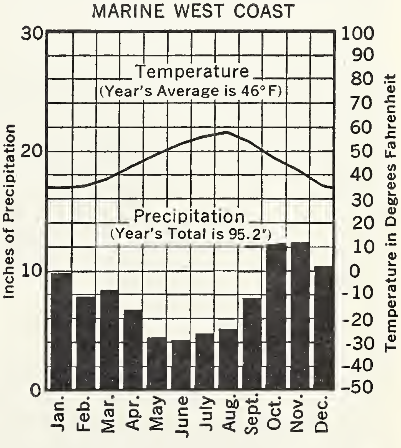


Fig. 17-3. This graph shows the climate of Prince Rupert, B.C. The cool but rarely cold temperatures and the fall and winter precipitation maximum are typical of marine west coast climates.

west Europe, southern Chile, Tasmania and southern New Zealand. Although typically equable, wide variations, particularly in Europe, are found. The chief characteristic is that this type is dominated by maritime air masses for most of the year. The temperatures are consequently remarkably constant, and in winter, warm for the latitude. During the Christmas season at Victoria, B.C. or London, England, people may be able to play golf in temperatures ranging above 55°. The summers are moderately cool, with mean temperatures of the warmest months varying from 55 to 65°. The temperature range in summer is low and the maximum temperatures on most days does not rise much above 70°. Occasionally, tropical air displaces polar maritime air and extreme temperatures may then reach 100°. As already mentioned, the winters are unusually mild, especially in Europe where (unlike British Columbia) there is no mountain barrier to prevent the warm Atlantic air from penetrating into the heart of the continent. This warm air comes off the Gulf Stream (or North Atlantic Drift) and explains the fact that Bergen, Norway has a mean temperature in January of 36°, although it is nearly 1000 miles north of Montreal (which has a January mean of only 14°). The coolest months in the marine west coast climate have means ranging between 35° and 45°. The southwest coastal region of British Columbia is the only part of Canada that has a January mean above the freezing point. In such areas, severe frosts are rare and snow seldom lasts many days at sea level.

Cyclonic storms pass through the marine west coast areas in all months of the year bringing strong winds, rain, and considerable cloud. These storms are most severe in late fall and winter, when

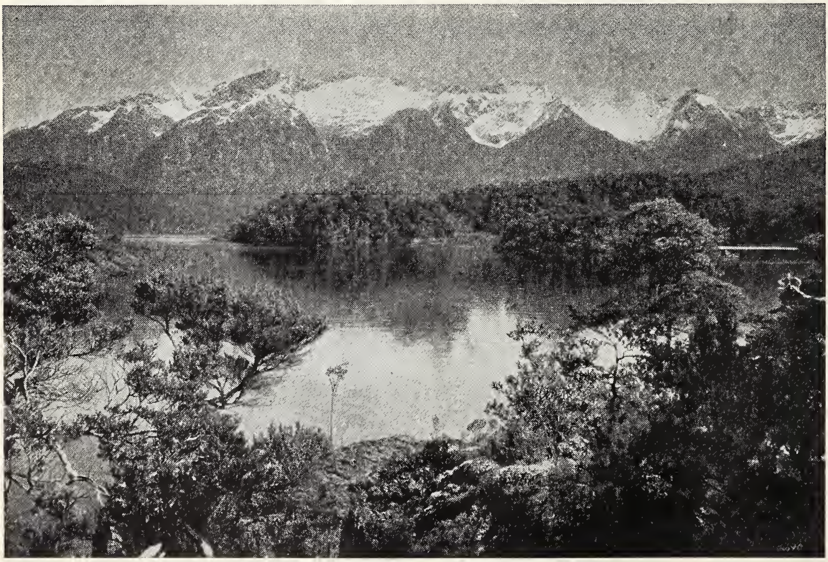
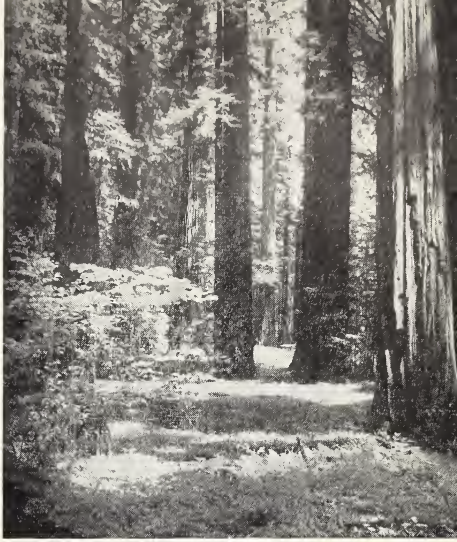


Fig. 17–4. A fiord in South Island, New Zealand. At sea level the marine west coast climate supports a luxurious vegetation, but in the mountains there are permanent icefields.

settled, clear weather rarely lasts more than 24 hours. Precipitation is well distributed throughout the year and drought is unusual. Due to the increased cyclonic activity in late fall, there is a tendency for maximum rainfall at that time. This is most marked in western North America. Total rainfall in the year varies from about 20 to 100 inches. Some stations in coastal British Columbia have recorded 200 inches in certain years, and this is the wettest part of Canada. The amount of rainfall depends upon distance from the sea and the position of highland masses which can produce orographic precipitation when the winds are forced to rise when passing over them. The narrow coastal area of British Columbia, already referred to, is the only part of the province (and of all Canada) falling into this climatic type. The rest of British Columbia experiences a mixture of climates that can best be described as a mountain climatic regime. Stations in the lee of the mountains may receive less than 30 inches of rain per year. Kamloops, for example, has a rainfall of only 10 inches. (Compare this with the figures for coastal stations quoted above. Prince Rupert in northern British Columbia receives 95 inches of precipitation annually.)

The natural vegetation in these areas of mild temperatures and moderate-to-heavy rainfall is forest. In western Europe, the vegetation in ancient times, before the land was cleared for farming, was mainly a broad-leaved deciduous forest with oaks, beech, elm, ash, and lime. In the Scottish Highlands and in Norway, coniferous trees were more important. The forests of Pacific North America are composed of large coniferous trees including Douglas fir, Sitka spruce and western red cedar. The forests of the Southern Hemisphere are similarly luxuriant although the species are very different. They are mainly broadleaf evergreen forests. Commercially, the North American area provides the best softwood lumber in the world. British Columbia produces nearly half of all the sawn lumber cut in Canada each year; the nearby states of Washington and Oregon produce a major part of American supplies. In other parts of the world that have a marine west coast climate, trees are generally of poorer quality or are too limited for extensive exploitation.



U.S. Forest Service

Fig. 17–5. Giant redwood trees flourish in the cool moist forests of the North Pacific Coast of the United States, a region of marine west coast climate.

There is a great variety of soils in this climatic region. The dominant soil is gray-brown in colour. This is the best forest soil in the world and responds well to careful cultivation. Although the cool summers and high humidities do not favour cereal growing, quantities of wheat, barley and oats are grown in the drier parts of northwest Europe. Intensive cultivation in this area permits the highest grain yields in the world. Eng-

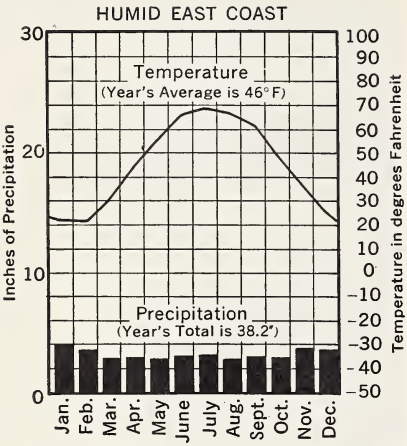


Fig. 17–6. The humid east coast climate covers large areas in east North America and east Asia. This graph for London, Ontario, shows the climate of a station in a cooler part of the region.

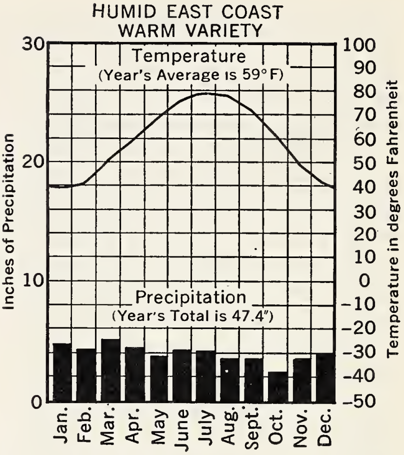


Fig. 17–7. In the southern United States, central China and south Japan temperatures are generally higher. This graph is for Nashville, Tennessee.

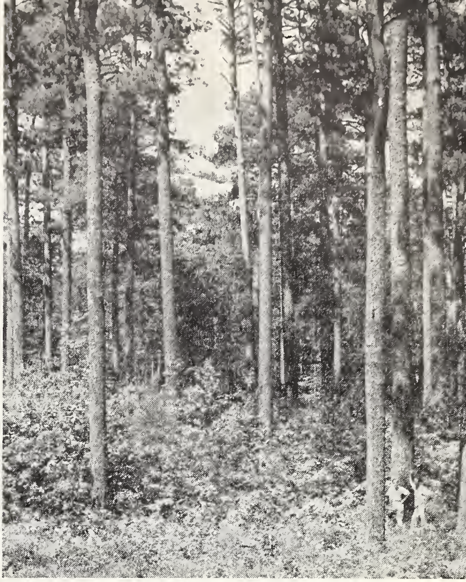
lish and Dutch farmers commonly obtain yields of 40 or even 50 bushels of wheat to the acre. In these countries, many other crops are grown besides grain, and highly mechanized mixed farming is the rule. In all areas with a marine west coast climate, grass is a valuable crop and dairy cattle are usually kept. Potatoes, vegetables, temperate fruits including apples and soft fruits grow well in the region. In the fertile Fraser delta of British Columbia, these crops are grown in market gardens, under intensive cultivation.

4. Humid east coast climate. This type occurs on the *east* side of the continents in roughly the same latitudes as the Mediterranean and marine west coast types. The humid east coast type covers broad areas in the Northern Hemisphere and smaller ones in the Southern. In spite of its name, this type is often found in areas very far from the sea. This is especially true in the Northern Hemisphere where, towards the west, the humid east coast type gradually changes into the dry mid-latitude type. As a result, such Northern Hemisphere areas have far more extreme climatic conditions than the humid east coast areas of the Southern Hemisphere. In the Southern Hemisphere, this type is found in southeast Australia, northern New Zealand and Uruguay. In our own hemisphere, the humid east coast type includes the whole of the United States east of longitude 100° W (excluding Florida), southern Ontario and Quebec, the Atlantic Provinces of Canada, central and northern China, Japan and Korea.

Summer temperatures are everywhere warm with mean temperatures in the warmest month between 70° and 80°. In the Northern Hemisphere, conditions are very humid during the warm months and the climate is distinctly tropical. The only cool areas in summer are the coasts with cold currents, especially the shores of eastern Canada and the Japanese island of Hokkaido. Winters in the Northern Hemisphere, except (as in southern Japan) where marine influences are dominant, are cool or cold. No part of the region in eastern Canada has a mean January temperature above freezing, and similar conditions are found in northern China. Farther south, winter temperatures are higher, but all areas experience occasional outbreaks of very cold air with strong northwesterly winds. In the Southern Hemisphere, the much narrower continents do not accumulate very cold air masses in winter and consequently temperatures are higher—between 45° and 55°. Frosts are consequently rare.

The precipitation of all areas falling into this climatic type is high. In most areas it is well distributed, although in Asia there is a marked summer maximum. In winter, the precipitation is mainly frontal in origin, as the result of passing cyclonic disturbances. In Canada, northern United States and northern China, most of the winter precipitation occurs as snow. The snowfall reaches a maximum in eastern Canada where large areas, including the cities of Montreal, Quebec, Edmundston, Charlottetown and St. John's receive over 100 inches annually. The summer rainfall is partly cyclonic and partly convectional in type. In Canada, the annual precipitation varies from about 30 inches in southern Ontario to 50 inches in parts of the Maritime Provinces. In most other parts of this climatic region, similar variations are found. The precipitation is normally more than sufficient for agricultural purposes, except in the driest areas.

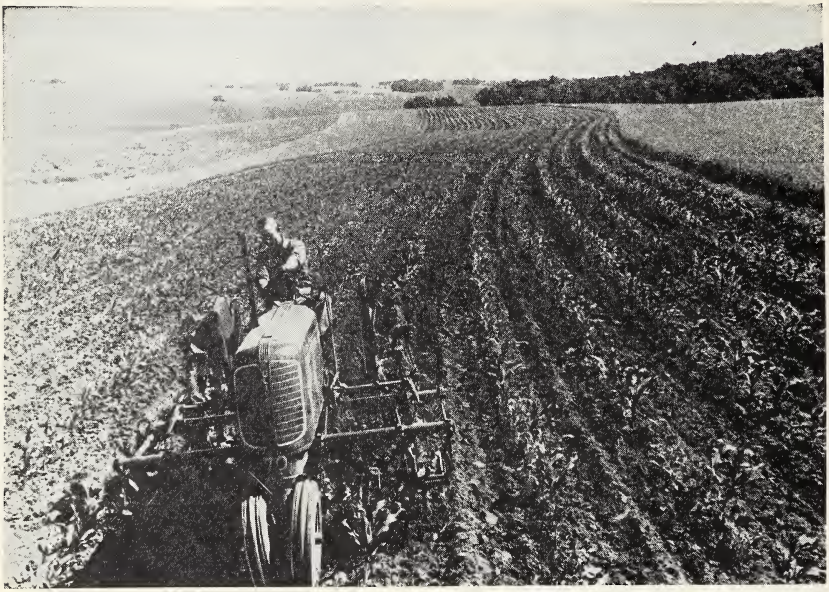
The natural vegetation of the humid east coast type is forest, except in the interior parts where it gradually gives way to prairie, as in southern Manitoba.



U.S. Forest Service

Fig. 17–8. Pine forest in the warm humid east coast climate of Arkansas. The height of the trees can be estimated by comparison with the men standing next to the tree in the right foreground.

The forests have a variety of types and characteristics. In eastern Canada, the natural vegetation is a mixed forest with small stands of single species, depending on the soil and local situation. The species include pine, spruce, balsam fir, birch, and maple. South of this mixed forest zone, in southwestern Ontario and north-central United States, is a deciduous forest belt with oak, chestnut, hickory, and yellow poplar. This in turn gives way in the southeastern United States to a pine forest. The forests of this climatic region in eastern North America were once of great value but, except, on the poorest soils, have been largely cleared for settlement. In southern Ontario, for example, it has been estimated that for every 100 acres of woodland that originally covered the area, only 10 acres remain today. Deforestation on such a scale has contributed

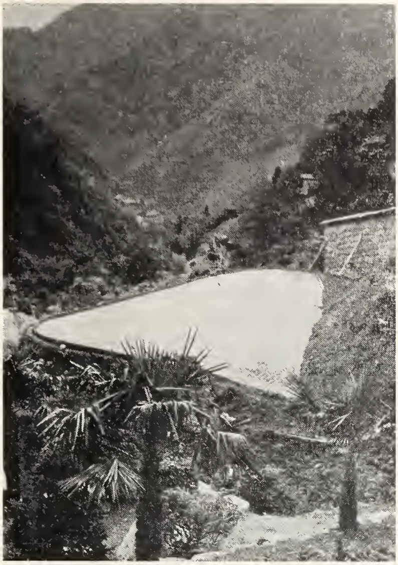


Courtesy Iowa Development Commission

Fig. 17–9. A cornfield on the prairies of the United States Mid-West. This area is on the western, dry edge of the humid east coast climate.

to the flood and soil erosion problems of this area. Many areas, however, still provide quantities of pulpwood, as in the Eastern Townships of Quebec, parts of New England, and the southeastern United States. The forests of this climatic type in other parts of the world are also variable. In Japan are found mixed coniferous and deciduous species, including broad leaf camphor trees and oaks in the south, pine, chestnut and maples in mid-Japan, and pine and fir in the north. In the southern hemisphere forests, evergreen deciduous trees such as the eucalypts and coniferous pines are found.

In the cooler areas of the humid east coast climate, soils are gray, gray-brown and brown. In more southerly areas, they resemble tropical soils, and are mainly red and yellow. Although the soils may be deep, the high degree of leaching due to heavy rain, along with low humus content, limits their usefulness. The first crops grown in eastern North America were the corn, squash and tobacco of the early Indians. Later cultivation of these crops, especially tobacco, by white settlers in the foothill (Piedmont) areas of the Appalachians, caused exhaustion of the soil and soil erosion. These were further factors in limiting the usefulness of the soils. Today, a much wider variety of crops is grown. In the cooler northern sections, grains, vegetables, fruits and grasses for beef and dairy cattle are cultivated. Farther south, wheat and cotton (in addition to the corn and tobacco already mentioned) are significant crops. The type of farming and the crops grown are different in eastern Asia,



G. Merrill

Fig. 17–10. A rice paddy in the mountains of the interior of the island of Shikoku, Japan. The climate is a warm variety of the humid east coast.

mainly because of the cultural history of the people; crops include rice, wheat, barley, millet, and beans.

5. Dry mid-latitude climates. So far, we have studied two mid-latitude climates in westerly locations and one in an easterly location. Can you name them? We shall now study two dry climatic regions found between these westerly and easterly varieties. These are: (a) the *mid-latitude grassland* and (b) *mid-latitude desert* climates.

The damper grassland climate is the more extensive of the two and is found in the drier parts of the Canadian prairies (southern Alberta and southern Saskatchewan), in the Great Plains of the United States and in the steppes of the Ukraine and central Siberia in the Northern Hemisphere. In the Southern Hemisphere, it is found on the pampas of the Argentine, the southern veld of South Africa and the downs of southeastern Australia. The climates of all these areas are dominated by continental air masses.

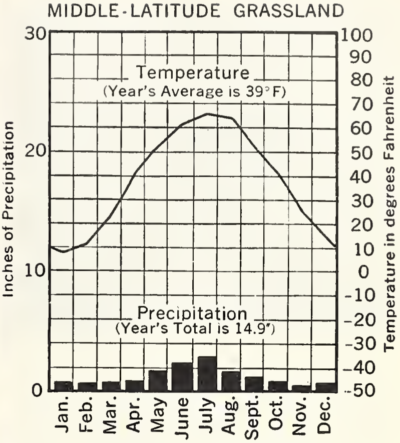
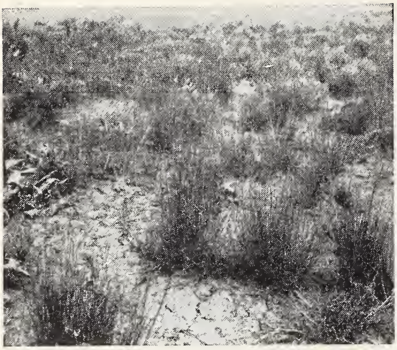


Fig. 17–11. There is a small area of the mid-latitude grassland climate in the driest part of the Canadian prairies. Swift Current, Saskatchewan, has cold winters, moderately warm summers, and a definite summer rainfall maximum.

In the Northern Hemisphere, the winters are cold, as arctic air masses from the north cover the regions. The Canadian prairies experience mean temperatures in the coldest months of −5° to 10°; they are higher in southern Alberta where the warming effect of the chinook is felt. In Siberia, it may be 10° to 20° colder than in Canada. Everywhere, the winters are clear and dry with occasional extremely low temperatures. In western Canada, snow falls from passing disturbances, but it seldom amounts to more than 50 inches—about one half of the total received in eastern Canada. In the southern hemisphere, mid-latitude grassland climates have warm win-



U.S. Forest Service

Fig. 17–12. Bluebunch wheatgrass growing on the Sheep Station Range in Idaho. This is a mid-latitude grassland.

ters, with mean temperatures above 50°. Snow and frost are unknown. The wettest months everywhere in this climatic region are in late spring or summer. The total precipitation is low, rarely exceeding 20 inches, and is often less than 15 inches. In southern Saskatchewan, about eight per cent of the precipitation falls in the five months from May to September. The northern parts of the region have cool summers with mean monthly temperatures of about 65°. Closer to the tropics, means of 75° and 80° are not uncommon.

None of the grassland climates receives enough precipitation for trees to grow except in favoured, moist sites, generally close to rivers. Very little natural grassland survives today; it has been ploughed up for arable land, or improved with imported grasses. Where it is still found, the grasses and associated plants generally form a continuous cover; in some places however, particularly in South America, the grasses are sometimes found in widely spaced bunches. Grassland soils are generally dark, black or brown in colour owing to their high humus content. The better grassland soils are some of the best in the world. Their main handicap is the danger of drought which kills the crops and makes the soil liable to wind erosion. During the 1930's, such conditions created the "dust bowl" regions found in Kansas, southwestern Saskatchewan and elsewhere. In recent years, drought conditions have returned on a major scale in some areas, notably the Texas "panhandle."

In North America especially, the settlement of the mid-latitude grasslands makes up one of the most fascinating chapters in the history of the continent. Originally, they were occupied by nomadic Plains Indians who were able to range widely over the prairie when they acquired the horse from the Spaniards. It is interesting to realize that the Pacific coast of the United States was settled *before* the Plains were. Indians, lack of wood, distance from the sea, drought and wind were the major factors that made them a barrier for decades and postponed their settlement. The first

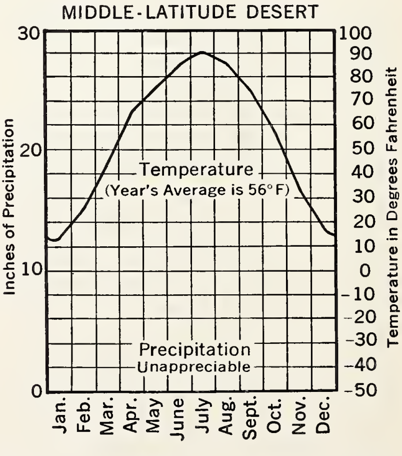
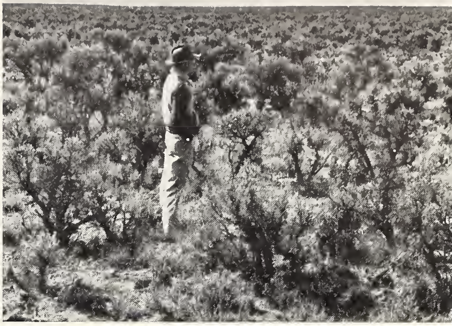


Fig. 17–13. This graph is from a station in the Gobi Desert of central Asia. The low winter temperatures should be compared with the tropical desert, Fig. 16–11.

settlers of the Plains were often ranchers and cowboys who grazed their stock on the vast, unfenced lands. Then farmers moved in, living in houses made of prairie sod, in a land lacking both timber and stone for building purposes. The invention of barbed wire made possible the fencing of the Plains, and the development of the windmill pump helped to overcome the lack of water. The coming of the railway enabled the settlers to bring in lumber and other necessary materials; it also enabled them to ship out their products. Thus the grasslands became a major source of cereals, particularly wheat, for the industrial areas of the world. In addition they still support large quantities of livestock—beef cattle in North and South America, sheep in Australia and South Africa.

During the early part of this century, "dry farming" developed in the more arid regions of the mid-latitude grasslands. Deep ploughing of the soil makes it possible for the land to retain much of the limited rainfall. The land is cultivated in strips, with each strip supporting a crop every two years. You may have seen pictures of "dry" farms, showing strips of wheat alternating with "fallow" or uncultivated strips. Successful attempts have also been made to irrigate part of the grasslands, as in the Lethbridge area of southern Alberta, and elsewhere. This makes it possible to grow a wider variety of crops such as sugar beets and alfalfa. The farmer is then not so dependent on a single crop such as wheat and he is less at the mercy of crop failure and world market and price conditions over which he has little control.

Mid-latitude deserts are limited to a few areas on the lee side of mountains, as in Patagonia, or the enclosed mountain basins as in the Great Basin of the United States and the Tarim and Turkestan regions of Asia. No true desert climate is found in Canada, although semi-desert conditions occur in the interior plateaus of British Columbia. Temperature conditions in these deserts are generally similar to the nearby grasslands, but summer temperatures may approach those of the hot deserts. Patagonia is an exception among the mid-latitude deserts in having cool summers. Rainfall is generally low—under six inches, and decreases to less than two inches a year in the driest areas. Agriculture is restricted to oases and other irrigated areas. The cold winters limit the type of crops that can be grown by irrigation in the mid-latitude desert. In the western United States an area with this climate in central Utah around Salt Lake City is an important producer of fruit and vegetables; the dry lands of the Columbia River basin have become one of the major wheat-producing regions of the world.



U.S. Bureau of Reclamation

Fig. 17–14. Sagebrush desert in Nevada.

6. Subarctic climates. In the Northern Hemisphere on the north, or poleward, side of the other mid-latitude climates is the subarctic. It is what geographers call a transitional climatic belt, gradually merging into the polar climates. The subarctic forms a zone extending across North America from

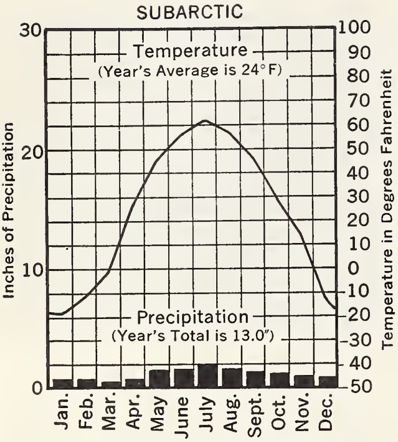


Fig. 17–15. This graph shows the climate of Fort Simpson, Northwest Territories. The subarctic climate has the greatest climatic extremes in the world.

Alaska to Labrador and in Eurasia from Scandinavia to the Pacific Ocean. The chief features of the climate are the long, cold winters and the short, but often warm, summers. Winter begins early in October when the mean daily temperature falls below the freezing point. The January mean temperature in the Canadian subarctic is between −15° and −20°. Every year minimum temperatures of −50° to −55° are experienced. The lowest temperature ever recorded in Canada was −81° in 1947, observed at Snag, Yukon. The Siberian subarctic is even colder. The average January temperature of a centre such as Verkhoyansk may fall to −60°; the extreme minimum recorded in this area is −90°. This is the lowest air temperature ever recorded on the earth's surface. In areas near the Atlantic Ocean (northern Quebec, Labrador and Scandinavia), the winters are cloudy and stormy with a high snowfall; elsewhere the snowfall is low, winds are light and the skies are often cloudless for long periods.

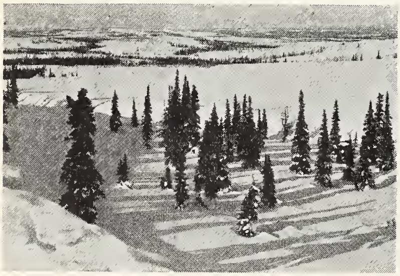


Fig. 17–16. The subarctic landscape of northern Quebec in the middle of winter. This picture shows open spruce woodland, common in the northern areas of this climatic type.

Spring is a very short season, lasting in some places only a week or so while the snow and lake-ice melt. Summer lasts from June until early September. The temperatures during this season (except near the Atlantic Ocean) are high, considering the latitude. In western Canada, the Mackenzie lowlands have a mean temperature in July of 60° or higher, and it is even warmer in parts of Siberia. One or two stations in the Mackenzie lowlands have recorded 100° —a reading higher than the highest temperature ever recorded at Montreal. The weather during the summer is often fine for long periods. Although this is the wettest season, the number of hours with rain is low. The annual precipitation is normally under 20 inches in the interior areas and between 20 and 40 inches on the Atlantic side. The lower amounts are usually sufficient for plant and crop growth, because the period of warm weather mentioned above is neither long nor steady enough to cause too much evaporation. The higher amounts are excessive for the same reason. There is a good deal of land too boggy and swampy for cultivation, as in parts of the Clay Belt of northern Ontario and Quebec.

The natural vegetation of the subarctic is the boreal coniferous forest. The dominant trees are spruce and fir. Many stands of deciduous trees are also found, including white birch, poplar, and alder. They are especially numerous where the forest has been destroyed by fire. The soils are infertile, gray and acidic. Decay of the coniferous vegetation helps produce these acid soils. Poor drainage is common in the subarctic, and extensive muskeg and bog soils are found. Over large areas, glaciation has removed the soil, exposing vast areas of the bedrock, especially on higher land. The possibilities of settlement in the subarctic lands are slight, except along the southern edge and where valuable minerals are present. Farming is handicapped by the poor soils and the short frost-free period. However, the longer summer day helps to make up for the short season by providing more hours of sunshine daily than plants obtain farther south. On some lands in the clay belts of northern Ontario and Quebec, livestock are kept and potatoes grown. In scattered settlements along the Mackenzie River, gardens flourish and grains have been grown. The terrain of the subarctic makes the building of roads and railroads extremely difficult, and this has also held back settlement. The forest in the southern part of the region contains valuable lumber and pulpwood. This makes Ontario and Quebec the greatest producing area for newsprint in the world. Sweden is also a major producer of pulp and paper.

In these regions, such industries flourish under particularly suitable conditions. The great (coniferous) softwood stands yield the ideal raw material for making pulp and paper. The trees are generally not suitable for other purposes as they are quite small, often less than 10 inches in diameter. Winter conditions are excellent for cutting operations, as the logs are easily moved over snow and ice to nearby lakes and rivers. In spring, the lumberjacks "drive" the wood to the mills along the lakes and down the rushing streams which provide excellent transportation. The same waters produce the power on which the pulp and paper mills depend. The mills of these provinces are located along the southern edges of the coniferous forest, near good transportation by road, rail, and water. Most of the pulp and paper is exported to the United States. In the northern section of the subarctic region, conifers are widely spaced except along river valleys, and their growth is too slow to justify large-scale exploitation. Although 30 per cent of Canada's area is forested (most of it in the subarctic), at least half of this forest area cannot be used because it cannot be reached by road, rail or water, or because it is of poor quality.

HAVE YOU LEARNED THESE?

Meanings of: marine, continental, steppe, prairie, boreal coniferous forest, mallee, chaparral, maquis

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) How do we classify the mid-latitude climates? (*b*) Name the six mid-latitude climates. (*c*) Why are these climates more limited in extent in the southern hemisphere?

2. (*a*) Describe the Mediterranean

climate, and locate the regions that enjoy it. (*b*) Describe and name the winds found in this type. (*c*) How do the plants of the Mediterranean areas protect themselves against the summer drought? (*d*) Name the chief crops grown in this region.

3. (*a*) What are the features of the marine west coast climate? (*b*) Where does it occur? (*c*) Explain the importance of lumbering in the marine west coast region of North America.

4. (*a*) Describe the mid-latitude humid east coast climates. (*b*) How do they vary between the northern and southern hemispheres? (*c*) Describe the vegetation of eastern Canada as found in the humid east coast climate. (*d*) What are the main crops of this climatic type in Asia and North America?

5. (*a*) Where are the dry mid-latitude climates found? (*b*) What are their characteristics? (*c*) Distinguish between steppe (grassland) and desert. (*d*) What have been the main problems faced by man in settling this region? (*e*) What is dry farming? (*f*) Describe the success of irrigation in the Great Basin of the U.S.A.

6. (*a*) Describe the main features of subarctic climates. (*b*) Where do they occur? (*c*) What are the handicaps to farming and settlement in this region?

GENERAL QUESTIONS

1. Name the different types of climates found in Canada and state the location of each (see also Chapter 18).

2. Describe and locate the different climates of the United States.

3. Why is the climate of the Niagara Peninsula favourable for fruit-growing? Compare it with the interior valleys of British Columbia in this respect.

4. Make an analysis of the differences in climate shown by the graphs in Figures 17–6, 17–11, 17–13.

5. Why do Mediterranean regions have winter rains?

6. Montreal, Fort William and Memphis, Tennessee are in the humid east coast climate region. Locate them.

7. Why is there no subarctic climate in the southern hemisphere?

8. Why is it important that the precipitation of the mid-latitude grasslands falls mainly in spring and summer?

STUDENT ACTIVITIES

1. Write a full description of the climate of your local area

2. Make a set of climatic maps of Canada to show temperature, precipitation, and other climatic data for January and July

3. Compile a list of references (magazine articles, books etc.) on mid-latitude climates

SUPPLEMENTARY TOPICS

1. Weather Extremes in Canada
2. Mediterranean Agriculture
3. The Relation Between the Climate and Forests of British Columbia
4. The Gobi Desert
5. Patagonia
6. The History of Irrigation in Utah
7. The Prairies in the Eighteenth Century
8. The Settlement of the Great Plains
9. Subarctic Vegetation
10. Tourist Climates: (*a*) Florida (*b*) The Laurentians

Chapter 18

POLAR AND MOUNTAIN CLIMATES

1. Radiation and temperature. Polar and high mountain climates provide the most difficult environment in which man lives. Both have low temperatures and snow for at least part of the year. In polar regions the low temperatures in winter are a direct result of the few hours of sunlight or its complete absence very close to the poles; consequently the surface of the earth loses more heat by radiation than it gains from the sun, particularly when there is snow on the ground. Even in summer heat from the sun received on the ground in high latitudes is still limited, and cold seas, often with pack ice in them, glacier ice and the cold ground, help to keep air temperatures low. On the other hand, mountains particularly near the Equator receive large amounts of radiation, and the low temperatures are then a direct result of high altitude.

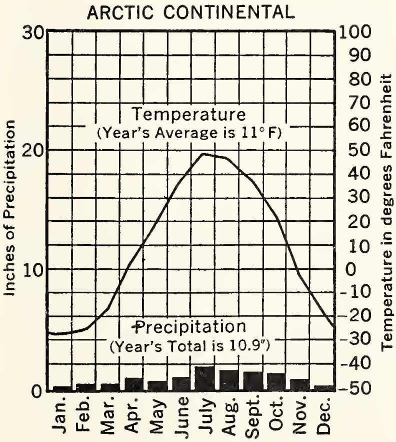
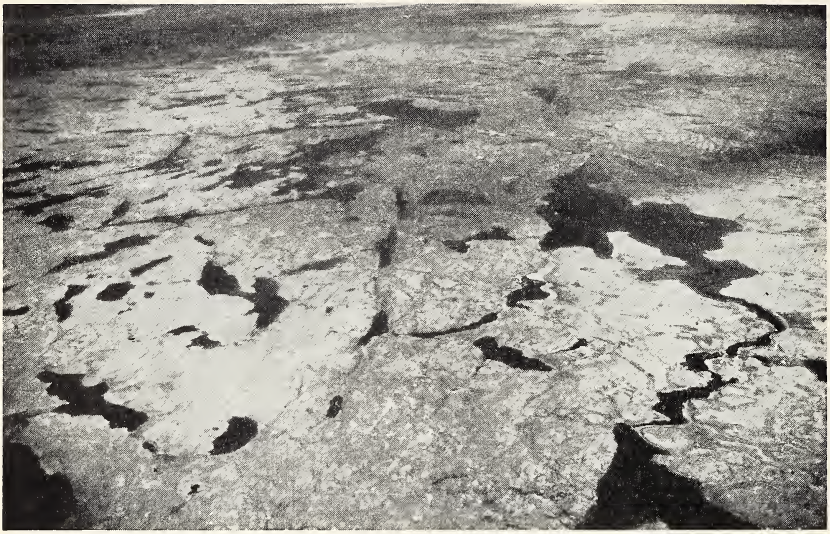


Fig. 18–1. The arctic continental climate of Chesterfield Inlet on the northwest coast of Hudson Bay. The long, cold winter is one of the most severe experienced in Canada.

2. Polar climates. There are numerous definitions of a polar climate. One of the most widely accepted is that if the mean temperature of warmest month fails to rise above 50° then the area has a polar climate. When the 50° isotherm for July is drawn on a map of the Northern Hemisphere it is found to agree closely with a line showing the northern limit of trees; because of the significance of trees to man and the great change in appearance their presence gives to the land, the tree line is often used to define the limits of the polar regions on land.

There are three main varieties of polar climates, *arctic continental, arctic maritime* and *polar icecap* climates. Canada has a larger area with a polar climate than any other country in the world.



Courtesy Royal Canadian Air Force

Fig. 18–2. Aerial photograph of the tundra of northwestern Canada.

Only the continental variety is found, and it covers between one-quarter and one-fifth of the total area of the country.

3. Arctic continental climate. The areas with this climate in northern Canada include the arctic islands, part of northern Quebec, and a triangular area of the mainland west of Hudson Bay and north of a line from Churchill, Manitoba to the Mackenzie River delta. The same climatic type is also found in north Alaska, and in a strip of land 100 to 400 miles wide along the north coast of the U.S.S.R. The winters are dark, long and very cold. Over wide areas of northern Canada the mean temperatures for January and February are below −20°. The extremes of cold are rarely greater than in the boreal forest to the south, but at many stations the temperature will fall below −50° sometime during the winter, and occasionally below −60°. The effect of the cold on people is often much greater than in the northern forests because of the lack of trees to give shelter from the wind. The winters are very free of cloud. Precipitation in the form of snow is light. Visibility on the other hand is often low because of blowing snow. In contrast the summer is a season of continuous daylight. The average daily temperature is between 40° and 50°, and away from the cold sea there may be fine, warm days with temperatures in the 70's. Most of the annual precipitation falls as rain during the summer. The total precipitation (rain and melted snow) for the year is low and is rarely above 10 inches. The summer is a cloudy, misty period particularly close to the sea.

The vegetation of the arctic continental climate is tundra. This term is applied to a complex group of species including flowering plants (such as the lupin in the western Canadian Arctic), lichens, mosses, grasses and sedges. The most striking characteristic of the Arctic

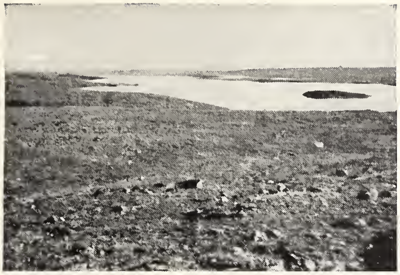


Fig. 18–3. The barren grounds of arctic continental Canada. Contwoyto Lake was visited by Hearne in 1771. Somewhere in this picture Franklin and his party buried their diaries when they were starving in 1821.

is the absence of trees. There are a number of woody plants including willows, dwarf birch and various kinds of berry bushes, and heather. These plants are dwarfed and restricted to areas where snow shelters them from extreme cold in winter and spring. The growing season for plants is short, often less than 2½ months and so the plant passes through its life cycle as quickly as possible often flowering a few days after the snow melts in June. Large areas of tundra are wet because the ground is permanently frozen (permafrost) a few inches below the surface and underground drainage is impossible. The tundra is inhabited by caribou, brown grizzly bears, white arctic fox, musk ox and wolves. During the summer it becomes the nesting place for vast numbers of ducks, geese and other migrant birds.

In North America the Eskimo were the original people to live in the polar lands. They were unable to grow crops because of the low temperatures and were always short of wood for implements and fuel. The majority of Eskimos have always lived on the arctic coasts where they can get fish and sea mammals for food, seal oil for fuel. Annual journeys inland are made to hunt caribou for food and clothing. In the Eastern Hemisphere there are few permanent native inhabitants of the tundra. In summer native peoples move from the forests to the tundra with their reindeer herds. The reindeer has been introduced into Alaska and more recently Canada, to replace the caribou with animals that can be herded.

4. Arctic maritime climate. The maritime variety of the polar climate is found in south Greenland, Iceland, Svalbard, the southern tip of South America, the Aleutian Islands, the Falkland Islands and some of the islands off the coast of Antarctica. There is no true arctic maritime climate in Canada, although the climate of Resolution Island and the coast of Labrador is similar to it. Typically this climate has cool, but not very cold, winters. There are no large sources of arctic continental air within these areas. Maritime air masses from adjacent seas give higher

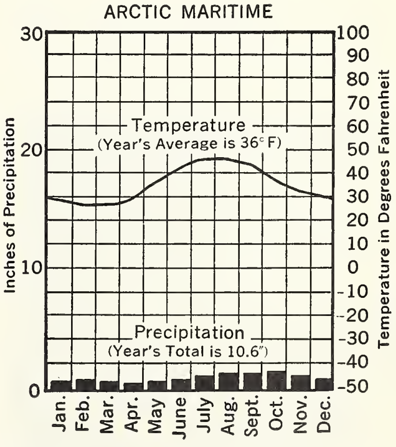


Fig. 18–4. This graph shows the climate of an arctic maritime station in Iceland. In contrast with Chesterfield Inlet (Fig. 18–1) the winters are warm.

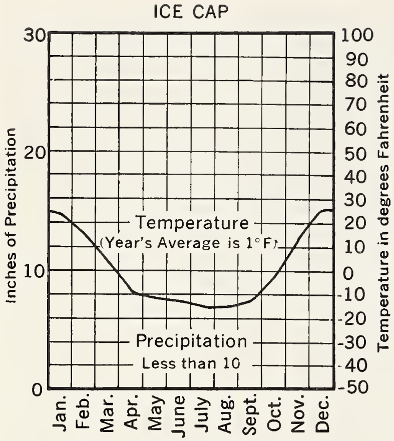
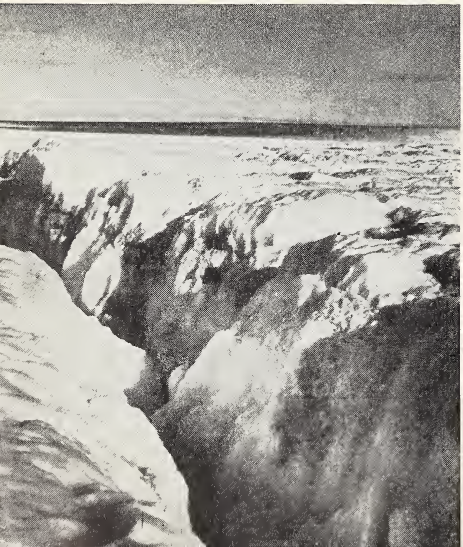


Fig. 18–5. Icecap climates are found in Greenland and Antarctica. They are the coldest in the world, with no month having an average temperature above freezing point.

temperatures than are found in the arctic continental climate. The mean temperature in the middle of winter is between freezing point and zero. Unlike the continental variety, the weather in winter is cloudy and foggy. Precipitation in the form of snow, or snow and rain, is heavy. The summers are cool, cloudy and damp.

Fig. 18–6. Crevassed surface of the Greenland Ice Cap, as photographed by the Victor Arctic Research Expedition.

Courtesy French Press and Information Service



Some crops including green vegetables, potatoes and very occasionally grain will grow in this climate. People who make their living from the land herd cattle or sheep and grow some crops for their own use. If the winter snowfall is heavy there is always a problem of collecting sufficient hay in the summer to last the livestock through the winter. Fortunately the neighbouring seas are generally rich in fish and important fishing industries have developed, particularly in Iceland and Greenland.

In the past the arctic maritime areas, except for the Aleutians and South America, were unoccupied by man. Iceland was uninhabited before the eighth century. In south Greenland Eskimos did not arrive until after Norsemen had colonized the coastal area from Iceland.

5. Polar icecap climates. The polar icecap climate is restricted to Greenland and Antarctica. Although there are small icecaps in arctic Canada and Svalbard, they are not large enough to make their own climate and they share the climate of the surrounding ice-free polar areas. Winter temperatures on the icecaps are similar to or colder than those in the arctic continental climates. The weather is generally calm and clear although there are occasional cyclonic disturbances that bring a light winter snowfall. In summer, although the sun is above the horizon for the whole 24 hours, the temperature rises slowly. The mean temperature of the warmest month fails to reach freezing point although the maximum temperature for a few days in the middle of summer may rise to 40° F. Under these conditions the snow never melts, except where rocks stick through. As the snow is buried under fresh falls it is gradually changed into ice, and eventually moves down to the sea as glaciers. The climates of both Greenland and Antarctica are modified by their elevation as the surface of both is nearly two miles above sea level.

6. Mountain climates. The mountain or highland type of climate differs from all the other climatic types, such as the tropical rainforest or Mediterranean climates, because of the great changes that occur in short vertical and horizontal distances. It has already been shown in Chapter 3, that air pressure decreases with height. At low elevations up to about 6000 feet the reduction in pressure is hardly felt unless the person is changing altitude quickly. At 17,500 feet air pressure is only half the quantity at sea level. Before this height is reached generally at about 13,000–15,000 feet, people from low altitudes begin to suffer with headaches and sickness from the low air pressure. After a few weeks most persons become acclimatized, unless the altitudes are over 20,000 feet when they will probably always feel the effects of the greater exertion necessary in physical exercise.

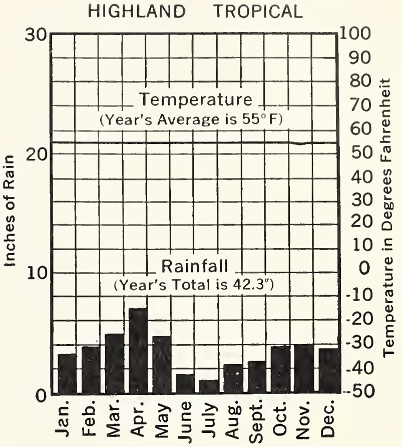


Fig. 18–7. In equatorial lands altitude may modify the climate so that it is pleasant for white people. Quito, Ecuador, has the low temperature range and rainfall distribution of an equatorial climate (see Fig. 16–1), but the temperature is nearly 25° lower.

Sunshine and radiation are greater in high mountain areas because of the thinner atmosphere and the absence of dust particles and moisture. An experiment in Austria showed that 40 per cent of the sun's ultraviolet rays striking the outer atmosphere penetrate to 10,000 feet, 31 per cent reach 5000 feet, and only 16 per cent sea level. It is therefore easier to be sunburnt and to tan at high altitudes, particularly when there is snow to reflect some of the rays. Although the radiation increases with altitude the air temperature decreases at approximately 1° F for 300 feet. We therefore find that Quito, Ecuador on the Equator and at an elevation of 9350 feet in the Andes Plateau, has a mean annual temperature of 55° whilst in the adjacent Amazon lowland, almost at sea level the mean temperature for the year is about 80°. Mount Washington, N.H. (6280 ft.) has an annual temperature of 26°, whilst adjacent valley areas have means of about 43°. Although the temperature may be low, it feels very warm in the sun and rocks become hot. The temperature drops quickly at sunset but extremely low temperatures are rarely recorded on mountains (although they may be on high plateaus) because the cold night air drains down into the valleys. In general the change of temperature with season is similar in a highland area to an adjacent lowlands, with the actual temperature difference remaining constant. The decrease of temperature with height is most important in tropical lands where highland regions are found in which European people may live in comfort.

Precipitation in mountains increases at first with altitude as the surface winds are forced to rise and orographic rain becomes important. In the tropics a height is frequently reached, above which the total precipitation begins to decrease again because the cool air now holds less moisture than it held at lower, warmer levels. The increased rainfall of highlands is of particular importance in arid areas. The heavier rainfall of the Andes provides irrigation streams for the Peruvian Desert, and the Tibesti and Ahaggar highlands are oases in the Sahara Desert. In the United States the waters of the Colorado River rising in the wet Rocky Mountains are used to irrigate a section of southern California. Generally the side of the mountains facing the rain-bearing winds is appreciably wetter than the sheltered, leeward side. Similarly the valleys and the inland mountain ranges are drier than the coastal area. In central British Columbia the windward slopes of the Coast Range even at sea level receives nearly 100 inches of precipitation a year and the higher parts probably over 200 inches. The leeward side, however, has 45 inches and the interior plateaus, 10–20 inches.

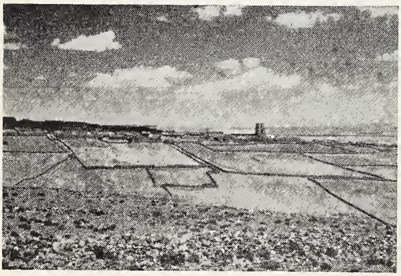


Fig. 18–8. A rural scene on a plateau in the Peruvian Andes. The absence of trees, and the very rocky ground which has been cleared to make walls near the village, should be noticed.

Winds are strong on exposed slopes in mountains but are light with long calm periods in the valleys. Local winds are a characteristic of many mountain areas. The winds flowing downslope by night, and upslope during the day are known as mountain and valley winds. Another type of local wind characteristic of mountains is the *foehn*, or as it is known in western Canada from the Indian word meaning 'snow eater,' the chinook. It is a warm dry wind particularly noticeable during winter that occurs in mountain valleys and on the leeward side of mountains as in Alberta. In Canada it occurs when low pressure system draws moist air from the Pacific Ocean over the Western Cordillera. In ascending the Coast Ranges the air loses much of its moisture but retains a good deal of its warmth. When it descends on the east side of the mountains it is heated by compression, becoming even warmer and drier. As it enters the prairies it temporarily displaces the cold winter air mass normally found there. The chinook is felt most strongly in Alberta and southwest Saskatchewan and penetrates occasionally to Regina. With the onset of the chinook, the temperature has been known to rise 40° in 15 minutes. In Calgary which normally has a maximum temperature of 28° in February, a temperature of 76° has been recorded. In the Alps this wind is known as a *foehn*, in Iran as the *Samun*, and in South Island, New Zealand as a *nor'-wester*.

7. Man in mountain lands. As temperature and precipitation vary so ab-

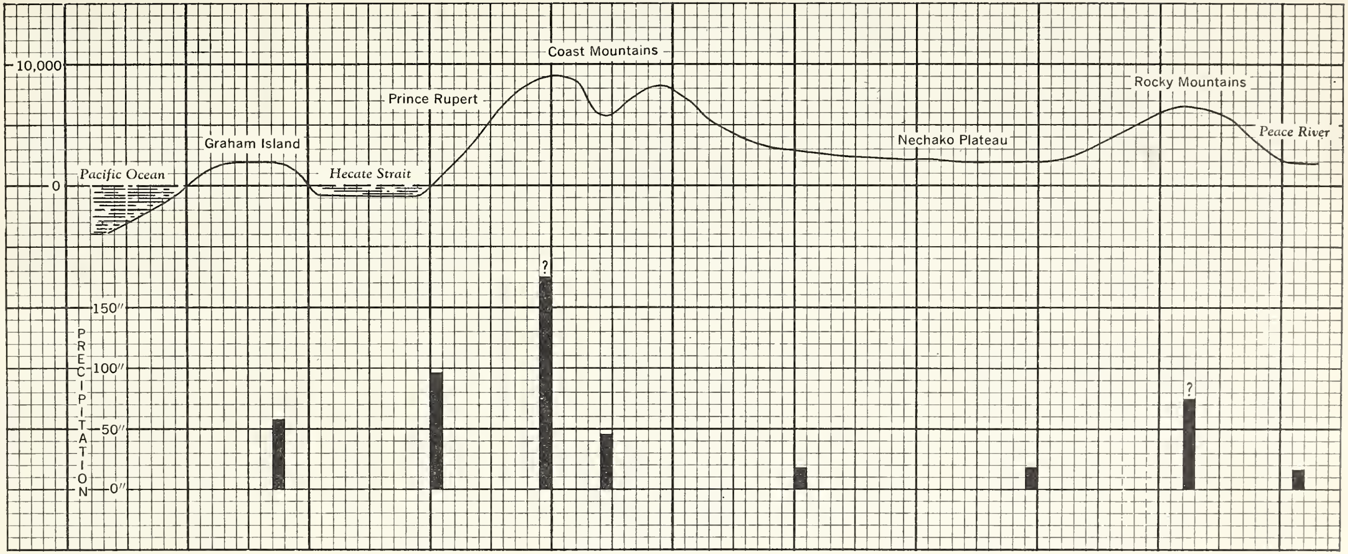


Fig. 18–9. A section across the mountains of western Canada in latitude 55° N, to show how the annual precipitation varies with relief and distance from the ocean.

ruptly in mountains it is not surprising that vegetation, farming and other human activities also change quickly. In the Alps, it is not unusual for a farmer to have land on the damp valley floor where there is pasture and hay for cattle. On the lower slopes of the valley he may have vineyards, and on the north side (where the sun reaches even in winter) his village house may be found. Higher up, if there is sufficient flat land, wheat may be grown. Above these cultivated areas is the forest zone, first of deciduous and then coniferous trees, where firewood and lumber are cut and pigs are turned loose to root. Finally, on the highest slopes, above the tree line, are the alpine meadows where in summer the cattle are taken to graze. The seasonal migration up the slopes in spring and down again in the fall is known as transhumance. It used to be practised in most mountain areas of Europe and Asia, but it has become less important with changes in farming during the present century.

In tropical areas the variation of temperature and precipitation with altitude is even greater. Four main zones are found in the mountains of Latin America. The lowest, the *tierra caliente* (hot lands) are found up to 2000 or 3000 feet. Where the rainfall is high, there is tropical rain forest, and rubber, bananas and cacao can be grown. Above this zone lies the *tierra templada* (temperate lands) extending to about 6500 feet. The forest is not very different from the caliente zone. Coffee, maize, tea, cotton, tobacco and rice may be cultivated. From 6500–10,000 feet is the *tierra fria* (cool lands) where the forest gives way to scrub and grassland. Wheat, corn, lucerne and potatoes are grown and cattle grazing becomes an important industry. Finally at still higher elevations above the tree line is the *tierra helada* (land of frost). Of all these zones the tierra fria is most favourable to European settlement. In Mexico the population is four times as dense in the tierra fria as in the tierra caliente.

HAVE YOU LEARNED THESE?

Meanings of: radiation, tree line, icecap, tundra, ultraviolet rays, foehn, tierra fria, transhumance, orographic rain

Explanations of: the different type of climate and where they occur

Diagrams of: chinook wind profile, showing temperate and moisture characteristics from sea level on the windward side to base level on the leeward side; mountain profile, showing temperature and vegetation characteristics from base to top

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. What do polar and mountain climates have in common?

2. What is a good way of defining polar climates? Where is the southern limit often placed? Name the three types.

3. What are the characteristics of arctic continental climates? Describe the vegetation found in them. How do Eskimos manage to survive in them?

4. What features are common to all arctic maritime climates? How does the maritime variety of polar climate differ from the continental type? Describe man's activities in arctic maritime climates.

5. What are the general features of icecap climates and where are they found?

6. What are the main characteristics of mountain climates? What is the effect of altitude on a person?

7. Describe how man's activities vary with height in mountain areas. Mention the altitudes and expressions used to describe the temperature characteristics of mountain areas in tropical lands.

GENERAL QUESTIONS

1. What are the weather hazards in polar climates, and how are they overcome?

2. Compare the climates of the western Canadian Arctic and Labrador.

3. Why is there no arctic continental climate in the southern hemisphere?

4. Why is the climate of Antarctica probably more severe than Greenland's?

5. Describe the succession of climates that would be met in going from sea level in the doldrums belt of Ecuador to the top of Mount Chimborazo (20,702 ft.), also in Ecuador.

6. In the above example what kinds of natural vegetation would be met?

7. Why are some mountain areas such attractive tourist areas?

8. Describe some of the special winds associated with mountains.

STUDENT ACTIVITIES

1. Keeping a scrapbook of pictures, articles and clippings that illustrate the climate of Arctic Canada
2. Compiling a list of references on climate and man's activities in mountains
3. Working out climatic graphs from data

SUPPLEMENTARY TOPICS

1. Plant and Animal Life of the Tundra
2. The Life of the Eskimo
3. The Life of the Reindeer Herders of the Old World
4. Polar Exploration
5. Fishing in Arctic Seas
6. Living in Northern Canada
7. Climates of the Past
8. Are Our Winters Becoming Warmer?
9. The Chinook Wind
10. The Climates of British Columbia
11. The Effect of Altitude on Mountain Climbers
12. Transhumance

INDEX

Absolute humidity, 55, 56, 57
Adiabatic lapse rate, 18
Air, composition of, 2; compression of, 5; humidity of, 5; properties of, 4; variations in, 5
Air masses, 80–86; analysis of, 83–85; characteristics of, 81; classification, 81; cold, 83; paths, 81; source regions, 81–82; warm, 82–83
Air pressure, 28–38; and humidity, 33–34; decrease, with altitude, 30–31, 179; gradient, 39–40; measurement of, 29–31; indication of, on maps, 32–33; and temperature, 33–34; units, 31; variations in, 33–35
Alaska Current, 128
Aleutian Islands, 178
Altimeter, 32
Amazon, climate of, 150–152
Anemometer, 41–42
Aneroid barometer, 31–32
Antarctica, 125, 178, 179
Anticyclones (see Highs)
Arctic continental climate, 176–177
Arctic maritime climate, 177–178
Argon, 4, 5
Arid regions, 77
Atmosphere, 2–6; exploration of, 2–4; extent of, 3, 4; heating of, 9–25; layers of, 3, 6; moisture in, 4, 5; phenomena in, 2–4; pressure of, 29–37
Auroras, 3, 4, 6

Barograph, 32
Barometers, 29–32; aneroid, 31–32; mercury, 29–30; and weather, 36
Bathyscaphe, 123
Beaufort scale, 43
Benguela Current, 127
Bergeron, T., 83
Bjerknes, V., 83, 95
Bora, 162
Brazil Current, 127
Brickfielders, 162
British Isles, climate of, 163–166
Bushman, 159

Cactus, 155, 159
California Current, 127, 128, 162
Campos, 156
Canada, yearly rainfall, 140; yearly snow, 141
Canadian Meteorological Service, 104–111
Canary Current, 127, 128
Carbon dioxide, in air, 4
Ceiling, 68–69
Centigrade, 20–21
Chaparral, 163
Chinook wind, 39, 169, 180
Cirrostratus clouds, 64, 65, 66
Cirrus, 63, 64
Clay belt, 172
Climates of the world, 143–149; altitude, 179–182; classifications, 143–146; middle-latitude, 161–174; polar, 175–179; tropical, 150–160
Climatology, 133–183
Cloudiness, symbols, 67–68
Clouds, 63–69; ceiling, 68; classification of, 64; color of, 117–118; descriptions of, 64–67; effect of, on temperature, 67; names of, 64–67; origin of, 63–64; symbols for, 64, 68
Cold front, 88–91
Color, of clouds, 117–118; of rainbow, 116-117; of sky, 117; of sun, 117; of sunsets, 117–118
Compression of descending air, 18, 77
Condensation, 61
Condensation level, 67
Condensation nuclei, 5, 69
Conduction, 12
Congo Basin, 150, 151, 152, 156
Continental shelf, 123
Continental Slope, 123
Contwoyto Lake, 177
Convection, 13–14
Cumuliform clouds, 64
Cumulonimbus clouds, 64, 66–67
Cumulus clouds, 64, 66
Cyclones, origin of, 95–96; pressure in, 35; rain in, 76; sources and tracks, 97, 98; typical, 96–97

Day, lengthened by refraction, 118
Descending air, 18, 77
Desert climates, tropical, 158–159; middle latitude, 169–171
Dew, 61–62, 159
Dew point, 61, 67
Divers, 122, 123
Doldrums belt, hurricanes in, 98–99; precipitation in, 76, 156; pressure in, 34; winds in, 44–45, 49
Drizzle, 71, 75
Dry continental climate, 169–171
Dry farming, 171
Dry ice, 78
Dust, bowl, 170; devils, 159; in air, 5–6

Equatorial rainforest, 150–152
Eskimo, 176, 177, 178
Evaporation, 54, 56
Expansion of rising air, 18, 76

Fahrenheit temperatures, 20–21
Fathometer, 122
Ferrel's Law, 40, 154
Floe ice, 125
Foehn wind, 39, 180
Fogs, 62–63; advection, 63; ground, 62–63; ocean currents and, 63, 128, 138; radiation, 62–63; steam, 63; upslope, 63; west-coast, 138
Freezing rain, 73
Frigid Zone, 143
Fronts, 87–93; characteristics of, 87; cold, 87, 90–91; definition of, 87; location of, 87; occluded, 91–92; stationary, 91; symbols, 87–89; warm, 89–90
Frost, 61–62

Glaze, 73
Greenhouse effect, 12
Greenland, 177, 178, 179
Gulf Stream, 126–128, 164
Gusts, 42

Hail, 74
Halos, 65, 117
Heat Equator, 21–22
Helium, 4
Highs, dryness in, 77; pressure in, 35; weather in, 102
Hooked trades, 49
Horizons, soil, 148
Horse latitudes, dryness in, 77; pressure in, 35; winds in, 45, 49
Humid east coast climate, 166–169
Humus, 97–99, 148
Hurricanes, 153
Hydrogen, 4
Hydrograph, 56
Hygrometer, 56

Iceland, 177, 178
Ice pellets, 73
Ice storm, 73-74
Icebergs, 125
Icecap climate, 178–179
Indonesia, 152
Insolation, 10; absorption of, 10–12; total, 24–25
International Ice Patrol, 125
Ionosphere, 3, 6
Irrigation, 159
Isobars, 33
Isothermal maps, 22–23
Isotherms, 21–25; in climate zones, irregularity of, 24–25; shifting of, 25; on world maps, 22–24

Japan Current, 127, 128
Jungles, 151

Karst, 162
Kennelly-Heaviside Layer, 3, 6

Labrador, 172–173
Land breeze, 48
Lapse rate, normal, 18; dry adiabatic, 18, moist adiabatic, 67
Latitude and rainfall, 136–137; and temperature, 132–133
Leaching, 148
Lead, in ice, 125
Leeward side, definition of, 41; dryness in, 77, 137–138
Leveche, 162
Lightning, 101–102
Line squall, 90–91, 101
Llanos, of Venezuela, 156
London, England, 164
London, Ontario, 164
Lows (see Cyclones)

Mackenzie lowlands, 172
Maquis, 163
Marine west coast climate, 143, 163–166
Mediterranean climate, 143, 161–163
Meteors, 3, 4
Middle-latitude climates, 144; 161–173
Midnight sun, land of, 143
Millibar, 31
Minerals, 124
Mirage, 115, 116
Mistral, 162
Monsoon, 154–155; effect, 47; summer, 47; winds, 47–48; winter, 47
Mountain, breeze, 48–49; climate, 179–182

Neon, 4, 5
Nitrogen, in the air, 4, 5
Noctilucent clouds, 3, 4
Norsemen, 178
North Atlantic Eddy, 128
North Equatorial Drift, 126, 127, 128

Oasis, 159
Occluded front, 91-92
Ocean, 122–128; basin, 123; currents, 122–128; deeps, 123; deposits, 124; depths, 122; floor, 124; ice, 125; minerals, 124; plateaus, 124; temperatures, 124–125
Ontario, climate of, 166–168
Oozes, 124
Oxygen, 4, 5
Ozone, 4

Pack ice, 125
Patagonia, 171
Pilot balloon, 41–42, 68
Pine forest, 167
Planetary wind belts, 43-46
Polar creep, 125
Polar easterlies, 45, 49
Polar front, 96
Polar highs, pressure in, 34; winds in, 45, 49
Precipitation, 72–79; areas of, 76; artificial, 78; forms of, 72–74; lack of, 76–77; measurement of, 74–75; symbols for, 75–76; world map, 77
Pressure gradient, 36
Prevailing westerlies, 45, 49, 77–78
Prince Rupert, B.C., 163
Psychrometer, 56

Quebec, climate of, 166–168

Radar, in exploring atmosphere, 4; to find ceiling, 69; in navigation, 111; and pilot balloons, 41
Radiation, 10–16
Radiosonde, 84–85
Rain gauge, 74–75
Rain shadow, 137–138; 180
Rainbow, 116–117
Rainfall controls, 135–138
Rainfall map, of Canada, 140; of the world, 77
Rainmaking, 78
Rawin, 84
Red clay, 124
Refraction effects, 115–116
Relative humidity, 52–59
Rime, 111

Sagebrush, 171
Sahara Desert, 156, 158–159, 180
Salt, in sea, 124
Santa Anna, 162
Sargasso Sea, 126, 128
Savannas, 155–158
Sea Breeze, 48
Selva, 151
Sheet ice or glaze, 73
Shifting of wind belts, 45–46
Silver iodide, in cloud-seeding, 78
Sirocco, 162
Sleet, 74
Smog, 69–70
Snow, 72–75
Snowfall, map of Canada, 140

Soil, classification of, 146–147; and climate, 147–148
Sounding, 122–123
South Equatorial Drift, 126
Specific heat, 12–13
Spectroscope, 4
Spectrum, solar, 116; radiation, 179
Spruce forest, 172
Squall line, 90–91
Station model, 1, 105–106
Stationary front, 91
Steppe, 169
Stratiform, 63, 89
Stratopause, 3, 6
Stratosphere, 3, 6
Stratus clouds, 64, 65
Subarctic climate, 171–173
Subpolar lows, pressure in, 34; winds in, 45, 49
Sun, shape of, 116
Svalbard, 178
Synoptic map, 104–107

Tarim desert, 171
Temperate Zone, 143–144
Temperature, of air, 16–19; inversion, 17–18; measurement of, 18–21; range, 15–17; representation on maps, 21
Temperature controls, 132–135
Theodolite, 41–42
Thermograph, 19
Thermometer, 18–21; liquid, 18–19; maximum, 19–20; scales, 20–21
Thunderstorms, 101–102
Tornadoes, 99–101
Torricelli, 29
Torrid Zone, 143–144
Trade winds, 153–154
Tropical climate, 150–159
Tropopause, 3, 6
Troposphere, 3, 6
Tundra vegetation, 176
Turkestan, 171
Twilight, 118
Twinkling of stars, 116-117
Twisters, 98
Typhoons, 98

United States Coast Guard, 125

Valley breeze, 48-49
Vegetation, of the world, 148–149
Veldt of South Africa, 169
Vertical rays of sun, 9–11
Victoria, B.C., 164
Visibility, 69

Warm front, 88–90
Warmest and coldest, hours of day, 15–17; months, 17
Water vapor, 54–59
Waterspouts, 99–100
Wave theory of cyclone, 95–97
Weather, and aviation, 111
Weather forecasts and services, 107–111
Weather map, 104–109
West Wind Drifts, 127
Wet-bulb and dry-bulb thermometer, 56
Whirlwinds, 41
Wind sock, 41
Wind vane, 41
Winds, 3–49; belts of, 43–46, 49; breezes, 48; deflection of, 40; Ferrel's Law on, 40; monsoon, 47–48; naming, 40–41; observing on maps, 41–42; origin of, 39–40; shifting of belts, 45–46; and weather, 41; world maps of, 50–51
Windward side, definition of, 40–41; rain in, 137–138, 153, 165, 180
World pressure belts, 34–35

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